

ADA033344

12



Rockwell International

DDC  
RECEIVED  
JUN 6 1977  
UNRECEIVED  
D

DISTRIBUTION

Approved for  
Distribution Unlimited



UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER 9 Final rept. 17 Aug 76 - 15 Jan 77	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) ON-WATER MOTION RELATIONSHIPS STUDY.	5. TYPE OF REPORT & PERIOD COVERED Final Report August 17, 1976 - Jan. 15, 1977	6. PERFORMING ORG. REPORT NUMBER NR76H-137
7. AUTHOR(s) 10 James D. Aurand	8. CONTRACT OR GRANT NUMBER(s) 15 N00600-76-C-1606	
9. PERFORMING ORGANIZATION NAME AND ADDRESS Rockwell International Corp. Columbus Aircraft Division Columbus OH-43216 11 15 Jan 77	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 12 101 p.	
11. CONTROLLING OFFICE NAME AND ADDRESS David W. Taylor Naval Ship Research & Development Center (DT-NSRDC) Bethesda MD-20084	12. REPORT DATE January 15, 1977	13. NUMBER OF PAGES 79
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) UNCLASSIFIED	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Unlimited Distribution		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES Dr. Robert F. Beck, Dept. of Naval Architecture, University of Michigan, Ann Arbor, Michigan provided Consultant Services and performed the motion analysis for the study.		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Sea Based Aircraft On-Water Motion Analysis (Head Seas) Sea State Relationships		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This report presents an on-water head seas motion analysis of three C/STOL and three V/STOL sea based aircraft configurations. Heave, pitch, acceleration, and slamming/wetness conditions are determined. Different forward speed conditions were studied. The effect of various configuration parameters (length, inertia, c.g. location, water plane area, etc) on head seas motion parameters was established. Sea state conditions from one to seven were studied. Fundamental sea state relationships and their effect on sea basing of aircraft are presented. Recommendations for subsequent model tank testing are indicated. (continued on other side)		

407396

20. ABSTRACT (Cont'd. from Page 1.)

Rockwell International Report NR76H-113, "Sea Based Aircraft Habitability Criteria" dated 15 October 1976, provides a definition of the human limits for sea based aircraft. Habitability criteria including vertical, lateral and roll limits for on-water operation are included. Motion sickness limits are presented. No serious habitability limitations were uncovered for the surface following sea based aircraft concept.

UNCLASSIFIED



Columbus Aircraft Division  
Rockwell International  
NR76H-137

#### ABSTRACT

This report presents an on-water head seas motion analysis of three C/STOL and three V/STOL sea based aircraft configurations. Heave, pitch, acceleration, and slamming/wetness conditions are determined. Different forward speed conditions were studied. The effect of various configuration parameters (length, inertia, c.g. location, water plane area, etc.) on head seas motion parameters was established. Sea state conditions from one to seven were studied.

Fundamental sea state relationships and their effect on sea basing of aircraft are presented. Recommendations for subsequent model tank testing are indicated.

This effort was performed under Contract N00600-76-C-1606, dated August 17, 1976 (Rockwell International Sales Order, S.O. 2395) to the David W. Taylor Naval Ship Research and Development Center (DT-NSRDC), Bethesda, Md., 20084.



Columbus Aircraft Division  
Rockwell International  
NR76H-137

## TABLE OF CONTENTS

<u>Section</u>	<u>Title</u>	<u>Page</u>
	ABSTRACT . . . . .	i
	TABLE OF CONTENTS . . . . .	ii
1.0	INTRODUCTION . . . . .	1
2.0	SUMMARY . . . . .	2
3.0	SELECTED SEA BASED AIRCRAFT CONFIGURATIONS . . . .	5
3.1	Configuration 1, CTOL Catamaran, 1.25M lb. TOGW . . . . .	5
3.2	Configuration 2, CTOL Single Hull, .769M Lb TOGW . . . . .	7
3.3	Configuration 3, C/STOL DT-NSRDC Model, 330 Lb TOGW . . . . .	7
3.4	Configuration 4, VTOL X-Wing, 25K Lb. TOGW. . . . .	7
3.5	Configuration 5, V/STOL Twin Boom, 40K Lb TOGW . . . . .	7
3.6	Configuration 6, V/STOL Twin Boom, 25K Lb. TOGW . . . . .	7
3.7	Configuration Head Seas Seakeeping Data . .	
4.0	HEAD SEAS ON WATER MOTION ANALYSIS . . . . .	14
5.0	DESIGN PARAMETER VARIATION EFFECT . . . . .	23
5.1	Configuration 1, CTOL Catamaran, 1.25M Lb. TOGW . . . . .	23
5.2	Other Sea Based Aircraft Designs . . . . .	27
6.0	MODEL TANK TEST PROGRAM RECOMMENDATIONS . . . . .	33
7.0	DEFINITIONS. . . . .	35
7.1	Wave Parameters . . . . .	35
7.2	Hull Parameters . . . . .	36
	REFERENCES . . . . .	39
	APPENDIX I	
	APPENDIX II	



Columbus Aircraft Division  
Rockwell International  
NR76H-137

## 1.0 INTRODUCTION

This study of Surface Loiter Aircraft On-Water Motion Relationships has been performed under Contract N00600-76-C-1606, dated 17 August 1976, to the David W. Taylor Naval Ship Research and Development Center (DT-NSRDC). The study includes the relationship of sea state characteristics to surface loiter aircraft characteristics, a head seas on-water motion analysis and a definition of human limits including habitability criteria of sea based aircraft on-water operation.

Rockwell International Report NR76H-113, "Sea Based Aircraft Habitability Criteria," dated 15 October 1976, provides a definition of the human limits for sea based aircraft. Habitability criteria including vertical, lateral and roll limits for on-water operation are included. Heating, ventilation, air conditioning illumination and volume limits are also included. Motion sickness limits are presented. No serious habitability limitations were uncovered for the surface following sea based aircraft concept.

This report presents (1) a head seas on-water motion analysis of six selected sea based aircraft configurations (three C/STOL and three V/STOL designs), (2) sea state relationships and (3) model tank test program recommendations for subsequent study.



Columbus Aircraft Division  
Rockwell International  
NR76H-137

## 2.0 SUMMARY

Reference 1 (NR76H-113), "Sea Based Aircraft Habitability," established 0.1 g's RMS as acceptable for sea based on-water mission operations. 0.3 g's RMS was established as unacceptable. Based on these limit criteria, (1) all of the sea based aircraft configurations considered in the study (except the 1.25 M catamaran) meet the acceptable criteria at zero speed in head seas at all sea states and (2) most of the study aircraft configurations approach or exceed the unacceptable motion criteria at 5 to 10 knots forward speed in head seas.

Acceptable sea based on-water operations are considered possible at very low forward speeds.

Sea following craft have acceleration of 0.10 to 0.125 g's RMS at zero speed in head seas at all sea states. At zero speed, accelerations do not increase significantly as sea state increases. Increasing on-water speed does increase the accelerations significantly; depending on the physical characteristics of the craft. Short length craft (e.g., 40 feet in waterline length) start contouring the waves at lower sea states than do longer length craft. This is shown in Figure 16 where representative 40 foot length craft start contouring the waves at sea state 3, and the 170 foot length craft starts contouring the waves at about sea state 6 ( $V = 0$  knots). As on-water speed increases to 5 knots, differences in craft length and radius of gyration in pitch ( $K_{yy}$ ) do result in different RMS acceleration levels.

The motion of sea following craft at 5 knots are higher in relation to those at zero speed and craft characteristics become more important. All craft have acceleration levels approaching 0.3 g's RMS at 5 knots or would reach this level at about 10 knots. Configuration 2, the .7 million pound single hull has about the same accelerations at 10 knots as the smaller craft do at 5 knots. The accelerations at the C.G. (not shown) are about half of those at the cockpit at 5 knots.

Recommended design limits for small 40 feet, 40,000 pound TOGW sea based aircraft are:

$$K_{yy}/L \leq .25 \text{ (Lowest inertia possible desired)}$$

This investigation has centered on the head seas condition. For a sea following craft, this would be the usual mode of operation to minimize rolling. An on water propulsion device will be required for craft orientation and for on water mobility.





Columbus Aircraft Division  
Blackwell International  
NR76H-137

At the lower sea states, the wind and waves are from the same direction. At the higher sea states or with long swell conditions the winds and waves may not be from the same direction. For those conditions, where the wind and waves are from the same direction, a large tail will tend to keep the craft headed into the wind (and waves) without necessitating active propulsion.

This is not to say that other modes of motion are unimportant (in particular rolling), but rather that head seas are usually the best case to examine, and is usually examined first. Sea keeping design studies in only head seas have been successfully conducted on ships for many years. Before final design, however, studies involving all modes of motion of the sea based aircraft should be carried out.

These computations are for long crested irregular waves in head seas. The important motions are pitch and heave. Had short crested waves been considered, the results would not be significantly different. Pitch and heave would still be the dominant motions. There would be some lateral motion (sway, roll, and yaw) but these are considered small. The energy in the waves coming from the lateral direction for short crested head seas is too small and the wave lengths too large to excite much roll motion in craft with reasonable float spacing. There is a possibility of non-linear phenomenon inducing extremely large roll amplitudes but this requires a highly unlikely combination of circumstances involving hull shape and wave length. These conclusions do not apply to the large CTOL catamaran, as initially configured, which was found to have unacceptable head seas motions.

In non-head seas, the roll motion becomes critical, due to the problem of wing tip submergence. The actual roll motion will depend on craft configuration (float span, roll inertia, damping, etc.) and wave exciting frequency. As with any lightly damped linear system, if the wave exciting frequency is near roll resonance, large motions will result. The roll natural frequency will depend on the roll radius of gyration and the transverse hydrostatic stability of the craft. The amplitude of the roll motion at resonance is a function of the roll damping (float size and shape, and perhaps wing tip flotation and shape). The more damping, the less the motion. Any analysis of the roll response of a configuration would have to take all of the above factors into account.



Columbus Aircraft Division  
Rockwell International  
NR76H-137

Unacceptable motions and g levels do occur at the cockpit for the configurations studied at speeds above 5 knots. Crew stations near the CG have about half the cockpit g's at speeds of 5 knots. Thus, long duration missions should consider very low forward speeds (for cockpit crew stations) and about 5 knots for crew stations near the CG. This places added emphasis on designing the craft for best in flight cruise performance and not for on-water cruising. Good aerodynamic cruise is obtained with fuselage length to beam ( $l/b$ ) ratios of 4 to 6. However, at these  $l/b$  ratios, conventional and STOL landings are more difficult and result in higher impact g's. This places added emphasis on VTOL operations to avoid these high impact g's and the weight penalties associated with hull shaping, steps, etc., needed for CTOL or STOL operation. Vertical and near vertical takeoff and landing operations need to be studied to establish desirable hull shapes and operational profiles.

Slamming and water coming over the bow have also been examined. In general, there is no slamming problem. However, all designs will have trouble with water coming over the bow in the lower sea state at 5 knots. At zero forward speed, deck wetting (water over the cockpit) is minimal. The best solution to decreasing water over the cockpit is to increase freeboard at the bow. A freeboard of 3 to 3.5 feet for small 40,000 lb craft was found to minimize water over the bow at zero speed.

This study did not consider bow shaping to minimize water over the bow or slamming. Subsequent detailed design will consider these aspects.



Columbus Aircraft Division  
Hickory International  
NR76H-137

### 3.0 SELECTED SEA BASED AIRCRAFT CONFIGURATIONS

In accordance with the Statement of Work for Contract N00600-76-C-1606, three representative C/STOL and three representative V/STOL surface loiter aircraft concept designs were selected by DT-NSRDC for on-water motion analysis. These configurations represent possible design concepts for sea based aircraft but are not necessarily optimized design configurations. These design concepts were selected to examine the on-water motions of a cross section of possible sea based aircraft design configurations. The general characteristics of the selected designs are presented in Table 1.

Table 1. Selected Design Characteristics

Design Number	Type	Name	TOGW		Span		Overall Length	
			(lbs)	(KG)	(Ft)	(M)	(Ft)	(M)
1	CTOL	Catamaran	1.25M	2.76M	317.3	96.7	327.0	99.7
2	CTOL	Single Hull	.769M	1.70M	222.7	67.9	237.9	72.5
3	C/STOL	DT-NSRDC Model	330*	727.7	9.6	2.9	8	2.44
4	VTOL	X-Wing	25K	55.1K	30.25	9.2	50.8	15.5
5	V/STOL	Twin Boom	40K	88.2K	63	19.2	55.8	17.0
6.	V/STOL	Twin Boom	25K	55.1K	50	15.2	44.2	13.5

\* 41,250 lbs. TOGW Full Scale

Configurations 1 through 3 are C/STOL concepts and 4 through 6 are V/STOL concepts.

#### 3.1 Configuration 1, CTOL Catamaran, 1.25M lb. TOGW

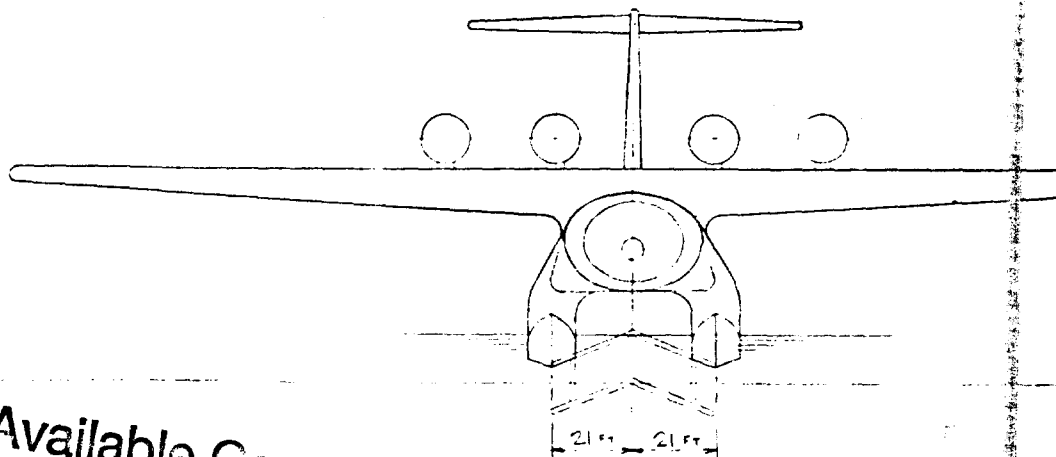
Configuration 1, shown in Figure 1, is a large 1.25 million pound TOGW conventional takeoff and landing catamaran sea based aircraft design. The configuration has a wing loading of 90 PSF and a wing area of 14,000 square feet. Considering an engine thrust of 80,000 lbs per engine, the takeoff thrust to weight is .256.

TOGW 125.10<sup>6</sup> LBS  
 SPAN 37.3 FT  
 LENGTH OVERALL 327.0 FT

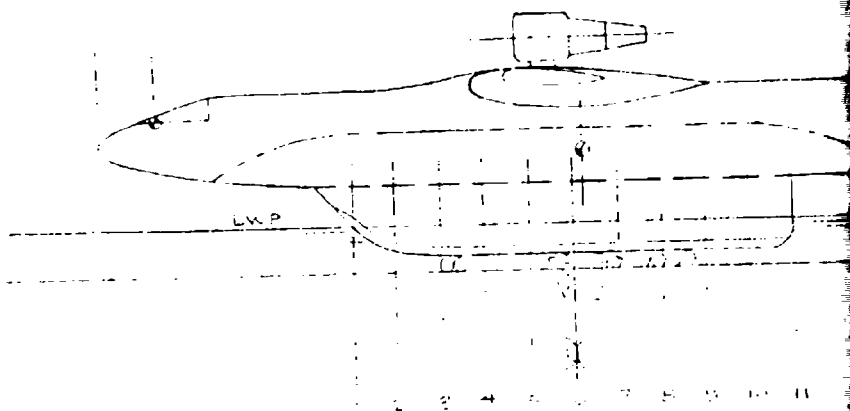
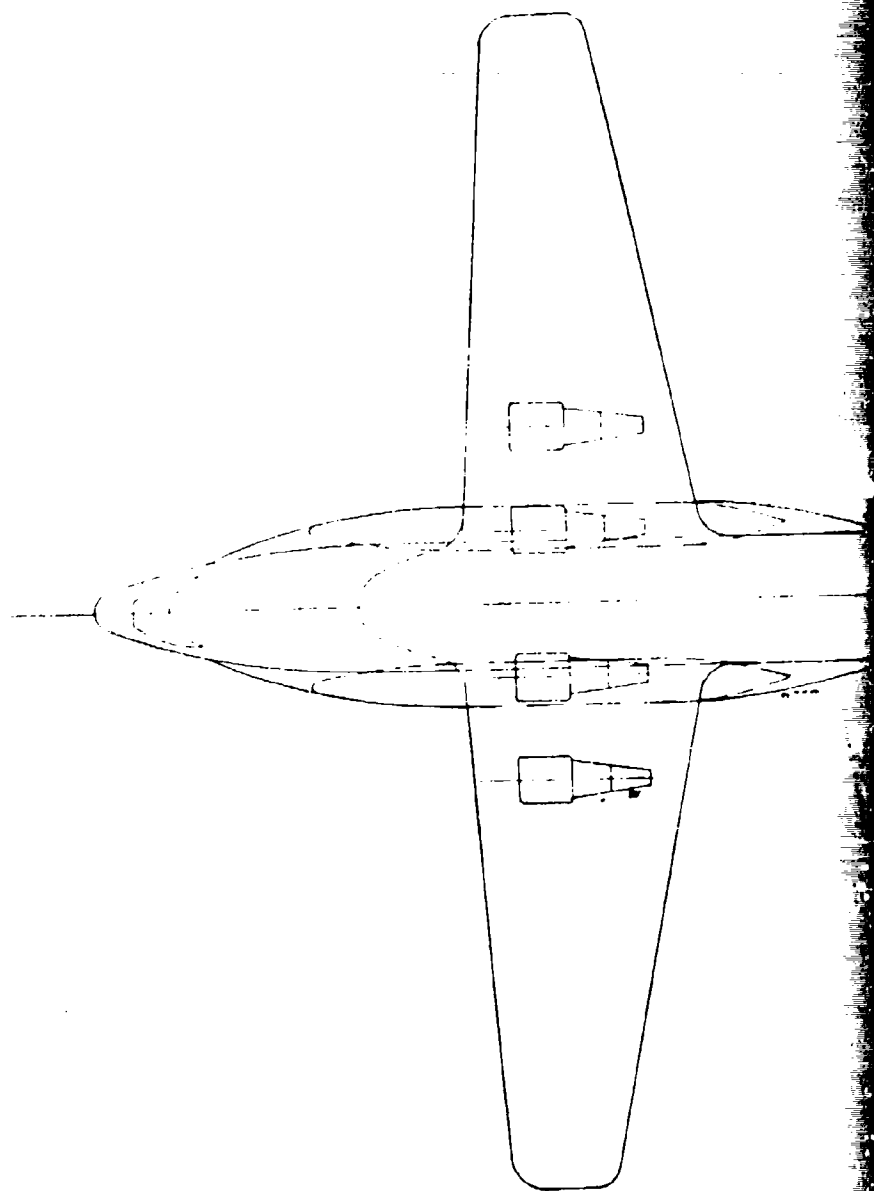
DATA FOR SEAKEEPING PROGRAM

NO OF STATIONS	11.0	} PER FLOAT
LENGTH	120.0 FT	
BEAM	12.0 FT	
DRAFT	9.75 FT	
XCG	-3.3 FT	
ZCG	-10.0 FT	
K <sub>xy</sub>	703.0 IN	
DOCKET LOCATION	115.0 FT FWD OF	
	30.0 FT FREEBOARD	

STN NO	BEAM (FT)	DRAFT (FT)	SECTIONAL AREA (F <sup>2</sup> )	DIST. 3-WAY STNS (FT)
1	0	0	0	
2	7	6.6	39.2	
3	10	7.5	65.0	
4	12	9.75	105.0	
5				STNS SPACED 12 FT APART
6				
7				
8				
9	12		105.0	
10	6.98	9.75	61.15	
11	0	0	0	

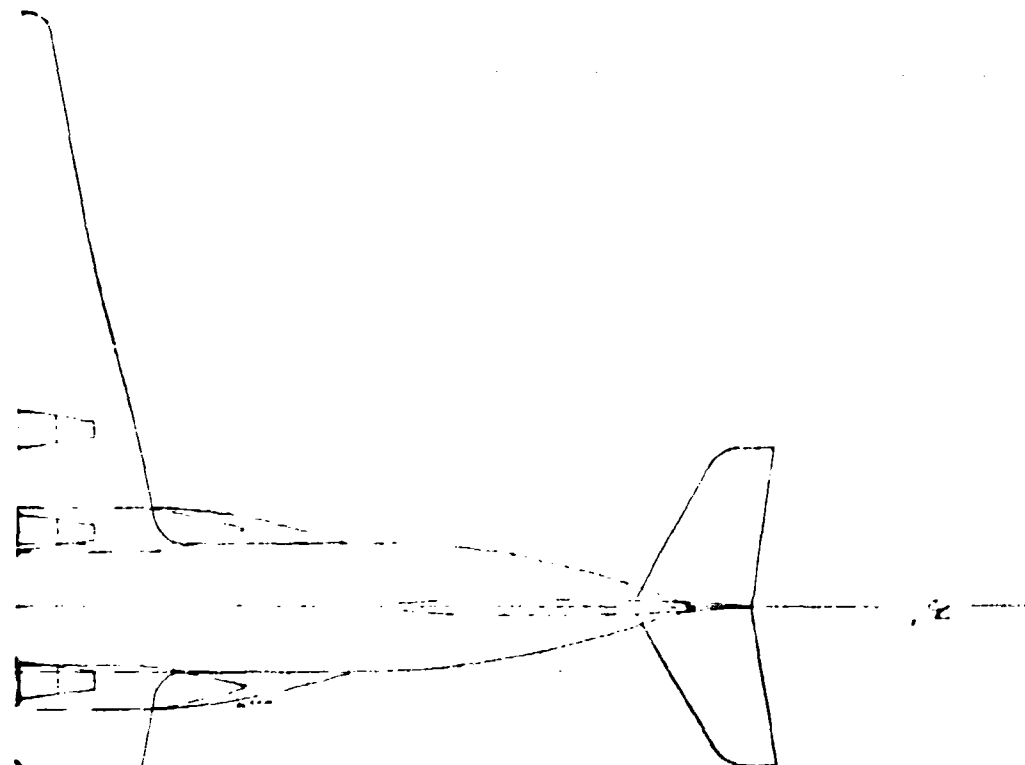


Best Available C



2 2 4 5 6 7 8 9 10 11

NR 76H



COPY AVAILA  
PERMIT TOLL



FIG

CON

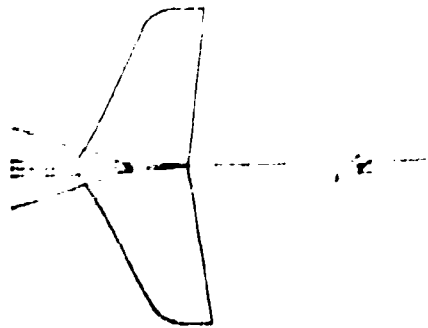
180

CTC

CAT

SCA

NR 76H-137



COPY AVAILABLE TO DDC DOES NOT  
PERMIT FULLY LEGIBLE PRODUCTION

FIGURE 1

CONFIGURATION 1

1801-018

CTOL

CATAMARAN - 1.55-1.10" LBS

SCALE 1/2" = 1' (1:12)



Columbus Aircraft Division  
Rockwell International  
NR76H-137

### 3.2 Configuration 2, CTOL Single Hull, .769M Lb TOGW

Configuration 2, shown in Figure 2, is a large 769,000 pound TOGW conventional takeoff and landing single hull sea based aircraft design. The configuration has a wing loading of 124 PSF and a wing area of 6,200 square feet. Considering an engine thrust of 41,100 lbs per engine, the takeoff thrust to weight is .214.

### 3.3 Configuration 3, C/STOL DT-NSRDC Model, 330 Lb TOGW

Configuration 3, shown in Figure 3, is a David W. Taylor Naval Ship Research and Development Center (DT-NSRDC) model configuration presently undergoing model basin tests. The model is a 1/5th scale model with a weight of 330 lbs. The full scale weight is 41,250 lbs.

### 3.4 Configuration 4, VTOL X-Wing, 25K Lb. TOGW

Configuration 4, shown in Figure 4, is a stopped rotor helicopter design with two outboard fans for forward flight and two internal inboard engines. The two internal inboard engines drive the outboard fans in forward flight on decoupling with the rotor. Static on water roll stability is provided by an active roll control mechanism not shown on the drawing. This could be provided with a small propeller mounted on a shaft below the helicopter. An engine start APU would be used for continuous on-water power for roll stabilization.

### 3.5 Configuration 5, V/STOL Twin Boom, 40K Lb TOGW

Configuration 5, shown in Figure 5, is a Type A class V/STOL configuration for use aboard vertical support ships and on-water. The concept includes a thrust augmented wing for vertical takeoff and landing and a propulsive wing concept for cruise flight. The configuration has a wing loading of 72.5 PSF and a wing area of 552 square feet.

### 3.6 Configuration 6, V/STOL Twin Boom, 25K Lb. TOGW

Configuration 6 is a scaled version of Configuration 5 (except for the cockpit area) and is representative of a Type C class V/STOL configuration for use aboard destroyers and on-water. The configuration has a wing loading of 71.4 PSF and a wing area of 350 square feet (see Figure 6).

### 3.7 Configuration Head Seas Seakeeping Data

The head seas on-water motion analysis was performed using the data contained in Figures 1 through 6 for the six respective configurations of Table 1. The head seas on-water motion analysis data is summarized in Table 2. Note that the pitch radius of gyration (Kyy) of configurations

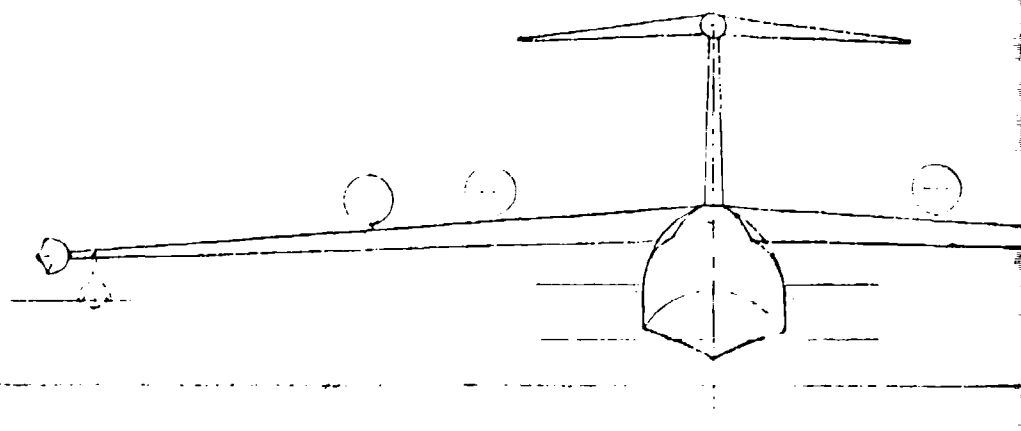


TOGW 769000 LBS  
 SPAN 222.7 FT  
 LENGTH OVERALL 237.9 FT

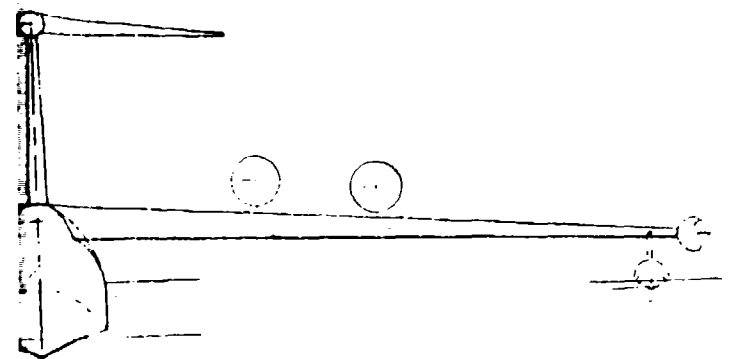
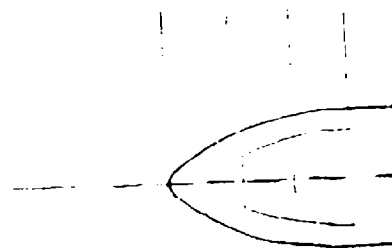
DATA FOR SEAKEEPING PROGRAM

NO OF STATIONS 17  
 LENGTH 170.0 FT  
 BEAM 25.0 FT  
 DRAFT 17.12 FT  
 X<sub>CG</sub> 3.38 FT  
 Z<sub>CG</sub> -7.0 FT  
 K<sub>WT</sub> 433.9 IN  
 COCKPIT LOCATION { 85.2 FT FWD OF L  
 { 16.5 FT FREEBOARD

STN NO	BEAM (FT)	DRAFT (FT)	SECTIONAL AREA (FT <sup>2</sup> )	DIST BTWN STNS (FT)
1	0	0	0	↑
2	14.6	3.5	26	
3	20.0	4.0	40	
4	25.0	4.8	69	
5	1	5.1	82	
6		5.6	95	STATIONS SPACED 10.625 APART
7		6.2	114	
8		7.0	127	
9		7.12	139	
10		7.10	101	
11		6.26	87	↓
12		5.52	69	
13	1	5.4	65	
14	25.0	4.0	50	
15	22.5	3.5	38	
16	18.0	1.7	29	
17	0	0	0	

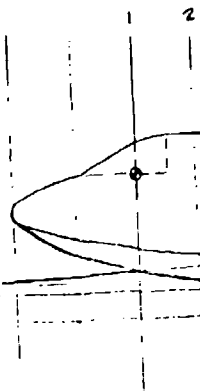


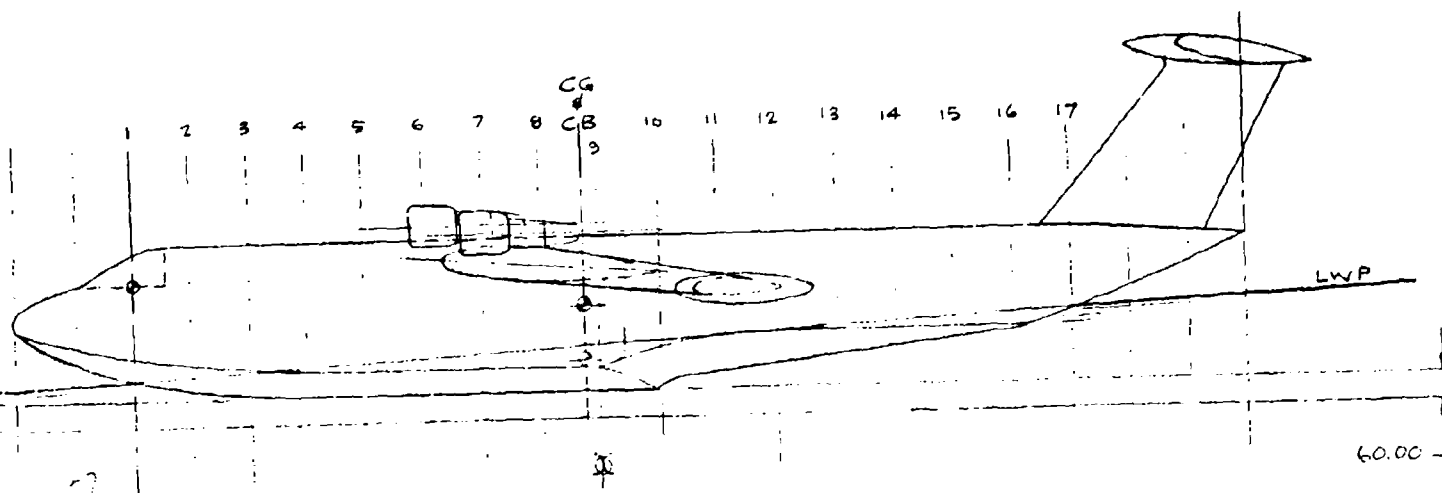
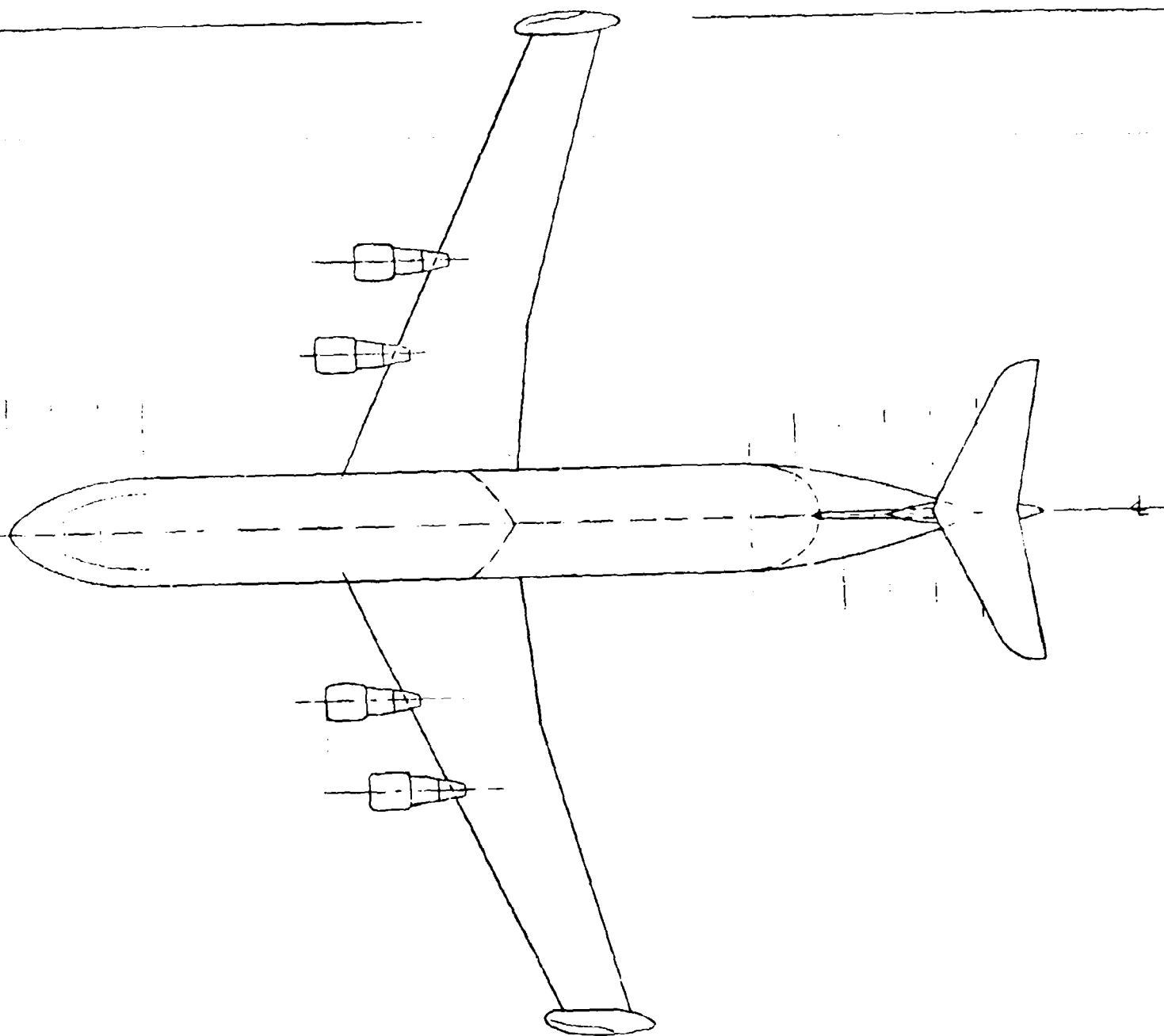
TW
77
025
000
025
000



REF. PLANE

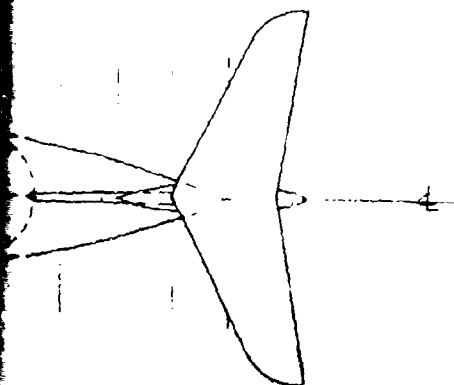
LV/P





0  
1  
2  
3  
4  
5-10-

NR 76H-137



COPY AVAILABLE TO DDC DOES NOT  
PERMIT FULLY LEGIBLE PRODUCTION

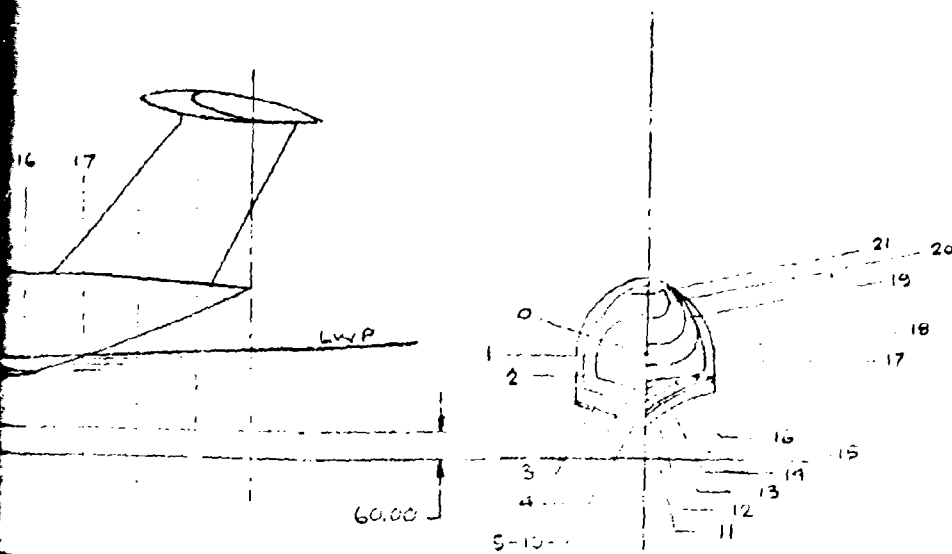


FIGURE 2

CONFIGURATION 2

8

1801-015

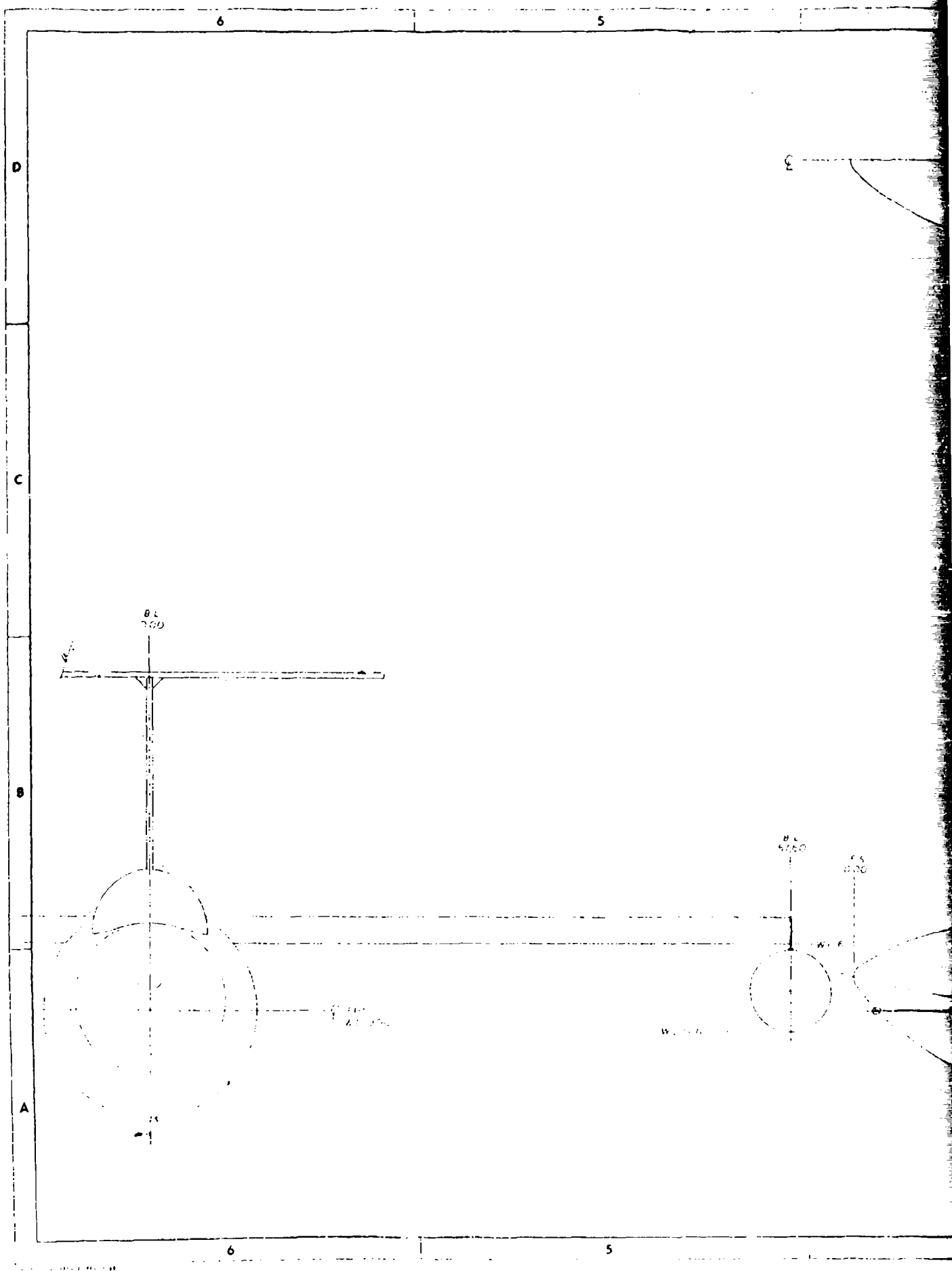
CTOL

SINGLE HULL - 769000 LBS.

SCALE - 1/240 (1" = 20 FT)

1 INCHES 9/30/76

4



4

3

2

FS  
46.50

FS  
30

FS  
66

FS  
000

FS  
90

WT 30

WT 3

WT 30

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
---	---	---	---	---	---	---	---	---	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	-----

2

1

REVISIONS

DISC PROX

NR 76H-137

COPY AVAILABLE TO DDC DOES NOT  
PERMIT FULLY LEGIBLE PRODUCTION

FIGURE 3

CONFIGURATION 3

NUMBER OF SHEETS DRAWN BY CHECKED BY DATE SCALE	NAME OF PIECE NO. 1 LIST OF MATERIAL QUANTITIES FOR ONE	MATERIAL NO. 2 NO. 3 NO. 4 NO. 5 NO. 6 NO. 7 NO. 8 NO. 9 NO. 10 NO. 11 NO. 12 NO. 13 NO. 14 NO. 15 NO. 16 NO. 17 NO. 18 NO. 19 NO. 20 NO. 21 NO. 22 NO. 23 NO. 24 NO. 25 NO. 26 NO. 27 NO. 28 NO. 29 NO. 30 NO. 31 NO. 32 NO. 33 NO. 34 NO. 35 NO. 36 NO. 37 NO. 38 NO. 39 NO. 40 NO. 41 NO. 42 NO. 43 NO. 44 NO. 45 NO. 46 NO. 47 NO. 48 NO. 49 NO. 50 NO. 51 NO. 52 NO. 53 NO. 54 NO. 55 NO. 56 NO. 57 NO. 58 NO. 59 NO. 60 NO. 61 NO. 62 NO. 63 NO. 64 NO. 65 NO. 66 NO. 67 NO. 68 NO. 69 NO. 70 NO. 71 NO. 72 NO. 73 NO. 74 NO. 75 NO. 76 NO. 77 NO. 78 NO. 79 NO. 80 NO. 81 NO. 82 NO. 83 NO. 84 NO. 85 NO. 86 NO. 87 NO. 88 NO. 89 NO. 90 NO. 91 NO. 92 NO. 93 NO. 94 NO. 95 NO. 96 NO. 97 NO. 98 NO. 99 NO. 100	U.S. NAVY STOCK NO. NO. 1 NO. 2 NO. 3 NO. 4 NO. 5 NO. 6 NO. 7 NO. 8 NO. 9 NO. 10 NO. 11 NO. 12 NO. 13 NO. 14 NO. 15 NO. 16 NO. 17 NO. 18 NO. 19 NO. 20 NO. 21 NO. 22 NO. 23 NO. 24 NO. 25 NO. 26 NO. 27 NO. 28 NO. 29 NO. 30 NO. 31 NO. 32 NO. 33 NO. 34 NO. 35 NO. 36 NO. 37 NO. 38 NO. 39 NO. 40 NO. 41 NO. 42 NO. 43 NO. 44 NO. 45 NO. 46 NO. 47 NO. 48 NO. 49 NO. 50 NO. 51 NO. 52 NO. 53 NO. 54 NO. 55 NO. 56 NO. 57 NO. 58 NO. 59 NO. 60 NO. 61 NO. 62 NO. 63 NO. 64 NO. 65 NO. 66 NO. 67 NO. 68 NO. 69 NO. 70 NO. 71 NO. 72 NO. 73 NO. 74 NO. 75 NO. 76 NO. 77 NO. 78 NO. 79 NO. 80 NO. 81 NO. 82 NO. 83 NO. 84 NO. 85 NO. 86 NO. 87 NO. 88 NO. 89 NO. 90 NO. 91 NO. 92 NO. 93 NO. 94 NO. 95 NO. 96 NO. 97 NO. 98 NO. 99 NO. 100
---	---	---	---

D

C

B

A

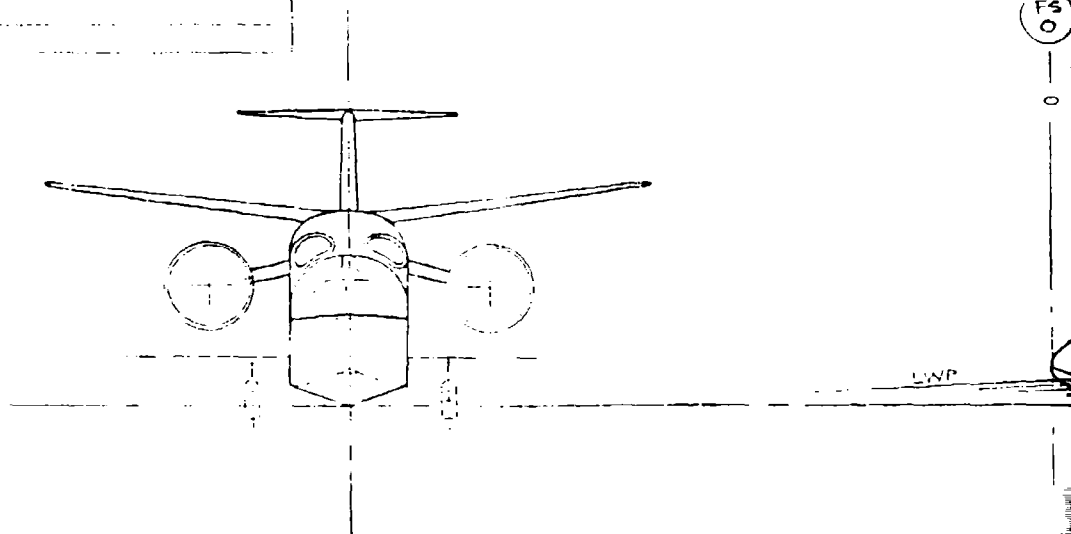
WORK REQUEST

PROJECT NUMBER

RENT TO BY

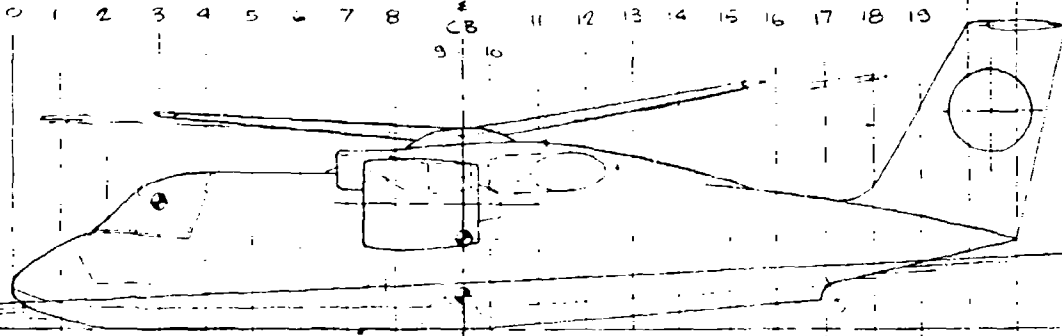
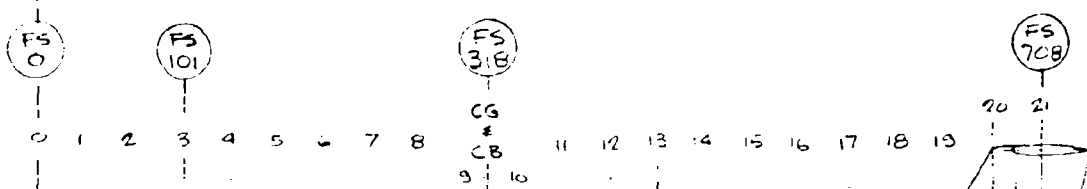
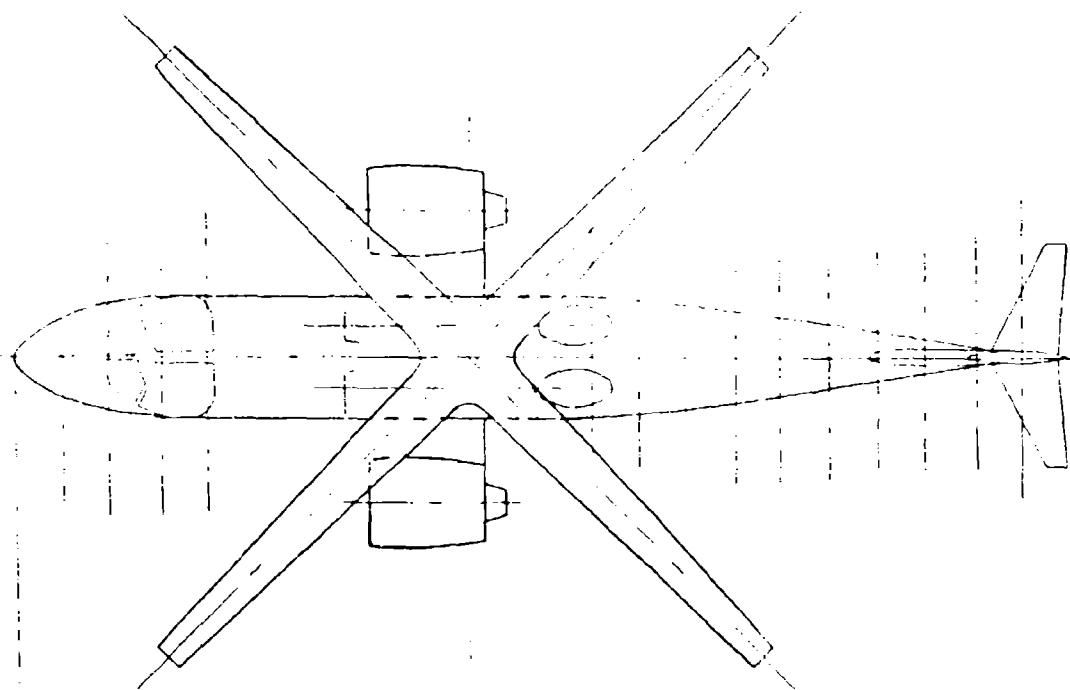
BEAM ..... 84 IN  
 DRAFT ..... 21 IN AT FS 0, 53 IN AT FS 708  
 LOAD WATER PLANE AREA ..... 44410 IN<sup>2</sup>  
 LOAD WATER PLANE CG ..... FS 260  
 CB ..... FS 318, 2 IN BELOW LWP  
 CG ..... FS 318, 64 IN ABOVE REF PLANE  
 COCKPIT LOCATION ..... FS 101, 66 IN FREEBOARD  
 MAX TAKE OFF GROSS WT. .... 40000 LBS  
 RADIUS OF GYRATION .....  $k_x = 18.48$  IN,  $k_y = 17.40$  IN,  $k_z = 24.16$  IN

21 SECTIONS EQUALLY SPACED BETWEEN FS 0 & FS 708		
SECT <sup>N</sup> NO	AREA (IN <sup>2</sup> )	BELOW LWP
0		
1	33	
2	82	
3	106	
4	140	
5	135	
6	149	
7	164	
8	178	
9	192	
10	185	
11	171	
12	159	
13	138	
14	125	
15	98	
16	78	
17	58	
18	16	
19		
20		
21		





PLAN



LWP

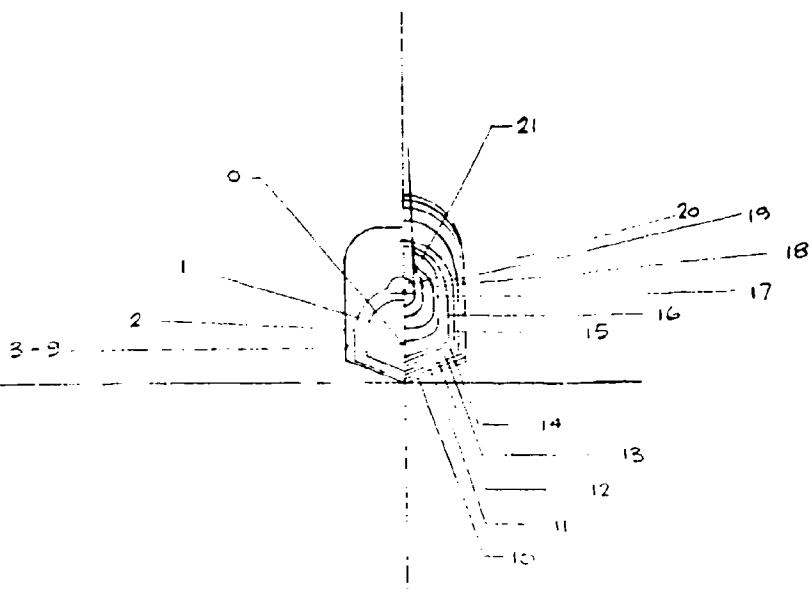
REF B

2

4

LWP

REF PLANE



5

NR76H-137

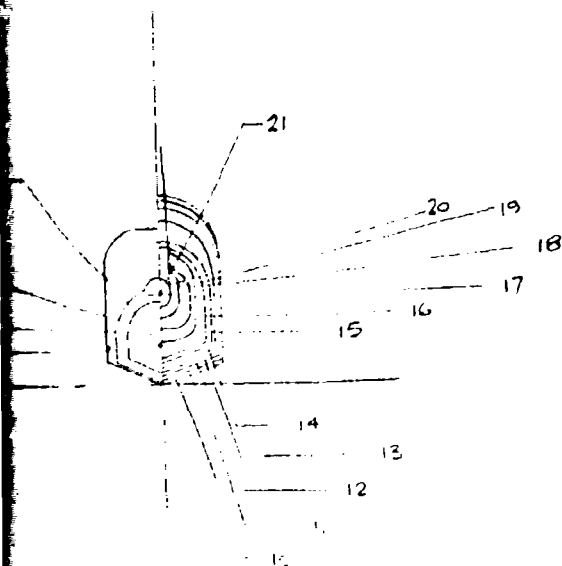


FIGURE 4

CONFIGURATION 4

1801-017  
SEA LOITER V/STOL  
"X" WING

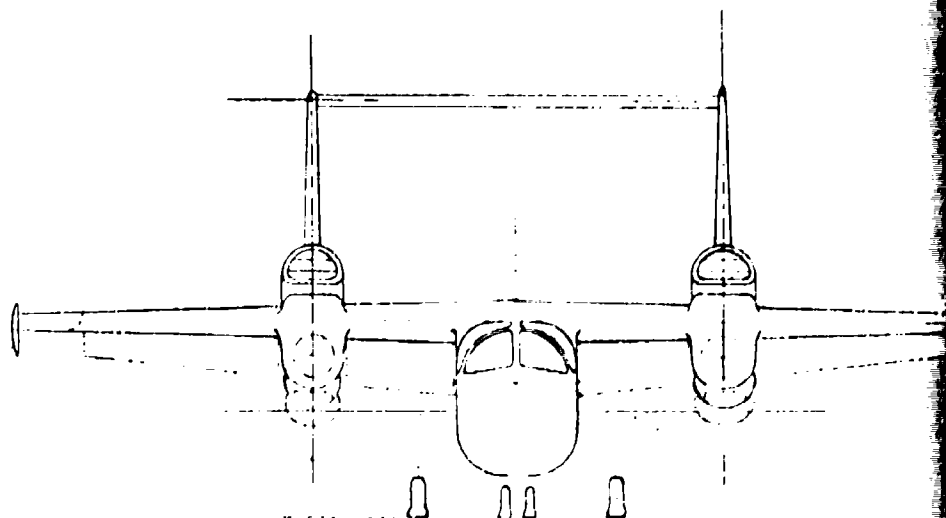
1/78 SCALE 0 100 200 300 IN. 10 4

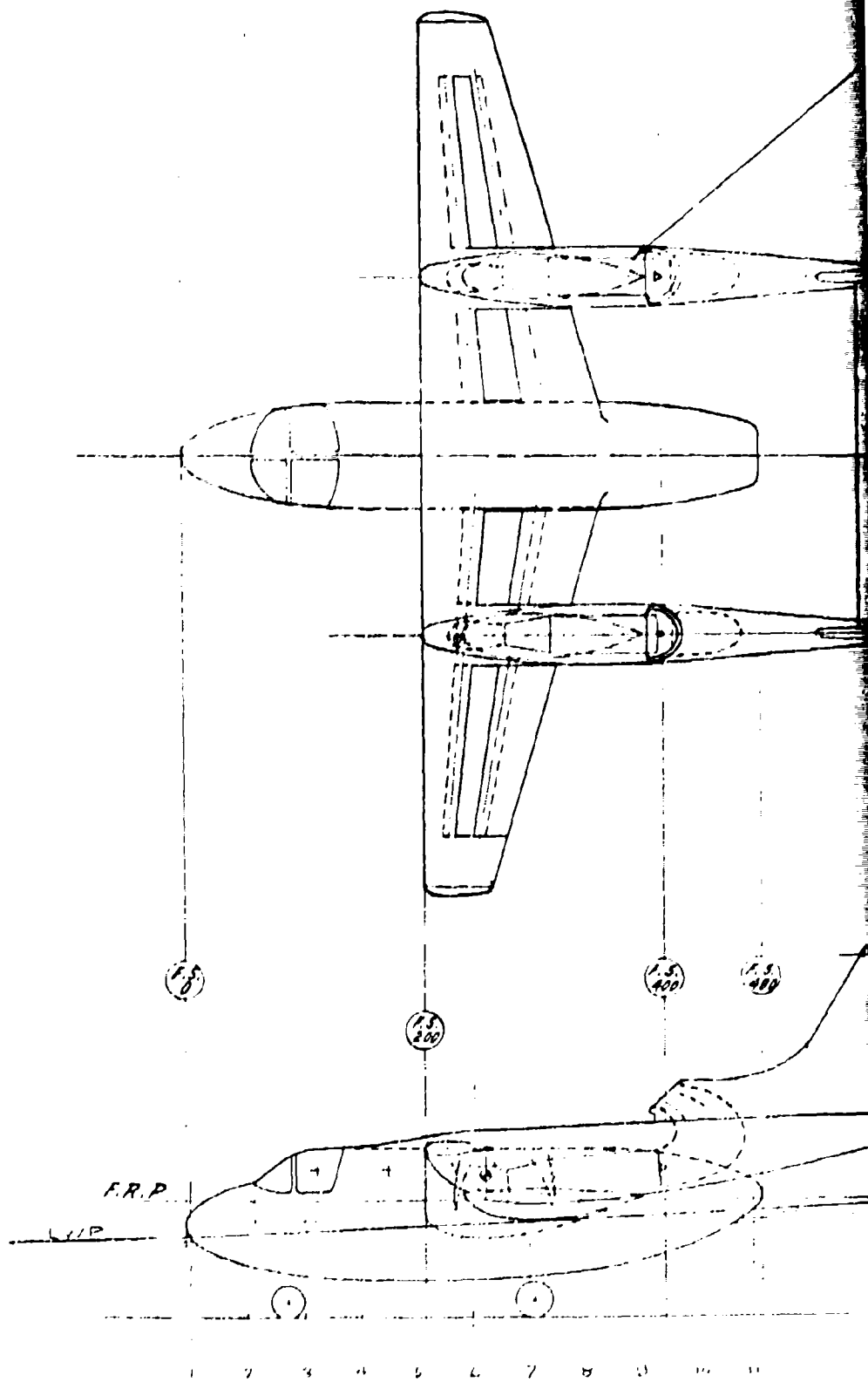
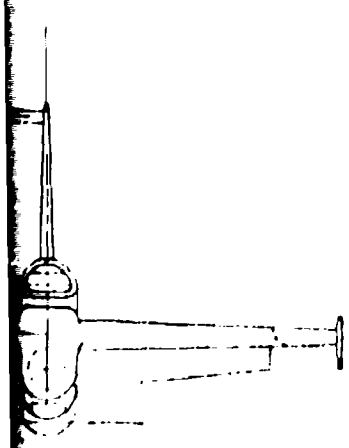
TOW 40000 LBS  
 SPAN 756 IN  
 LENGTH (OVERALL) 670 IN

# DATA FOR SEAKEEPING PROGRAM

NO OF STATIONS 11.0  
 LENGTH 475.0 IN (39.17 FT)  
 BEAM 88.0 IN (7.33 FT)  
 DRAFT 46.5 IN (3.8 FT)  
 YCG - 6.5 IN (-0.542 FT)  
 ZCG - 40.0 IN (-3.33 FT)  
 KVL 100.3 IN (8.34 FT)  
 CORRECT LOCATION { 66.0 IN FWD OF 1  
 34.0 IN FREEBOARD

STN NO	BEAM (IN)	DRAFT (IN)	SECTIONAL AREA (IN <sup>2</sup> )	LIST. BTWN STNS (IN)
1	0	0	0	
2	62	19	912	
3	80	31	2108	
4	88	35	2800	
5	86	39	3160	STNS SPACED
6	88	42	3400	47 IN
7	88	44	3520	APART
8	88	43	3440	
9	85	40	3080	
10	68	26	780	
11	0	0	0	





(2) PW 06 25 29/1.0 ENGINES

WING

Sw 552 ft<sup>2</sup>  
 R 6.7  
 λ 0.35  
 $\frac{LE}{c}$  0°  
 c/c 18% SC

HORIZONTAL TAIL

Sh 110 ft<sup>2</sup>  
 R 5.3  
 λ 1.0  
 $\frac{LE}{c}$  0°  
 c/c 12.5%

AUGMENTER (EA PANEL)

Az 4649 in<sup>2</sup>  
 Ao 310 in<sup>2</sup>  
 A/Ao 15  
 H/d 1.5  
 φ 1.65

VERTICAL TAIL

Sv(EA) 95 ft<sup>2</sup>  
 R 1.56  
 λ 0.38  
 $\frac{LE}{c}$  30°  
 c/c 10.5

B.P. 149

COPY AVAILABLE TO DOD DOES NOT  
 PERMIT FULLY LEGIBLE PRODUCTION

FIGURE 5

CONFIGURATION 5

1801 - C13

V/STOL SEABASED AIRCRAFT  
 PROPULSION WING TWIN BOOM  
 40000 LBS TOGW

SCALE - 1/40

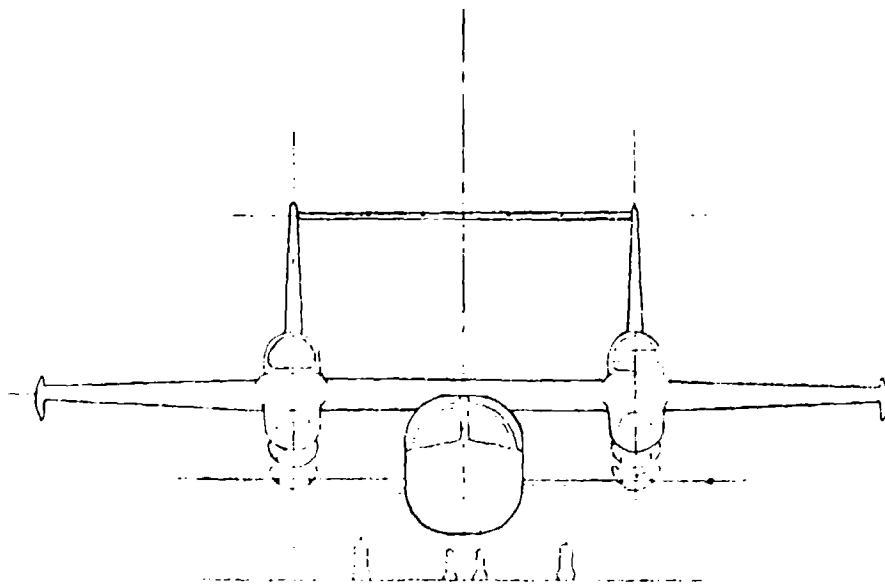
C. GREER 9/8/76

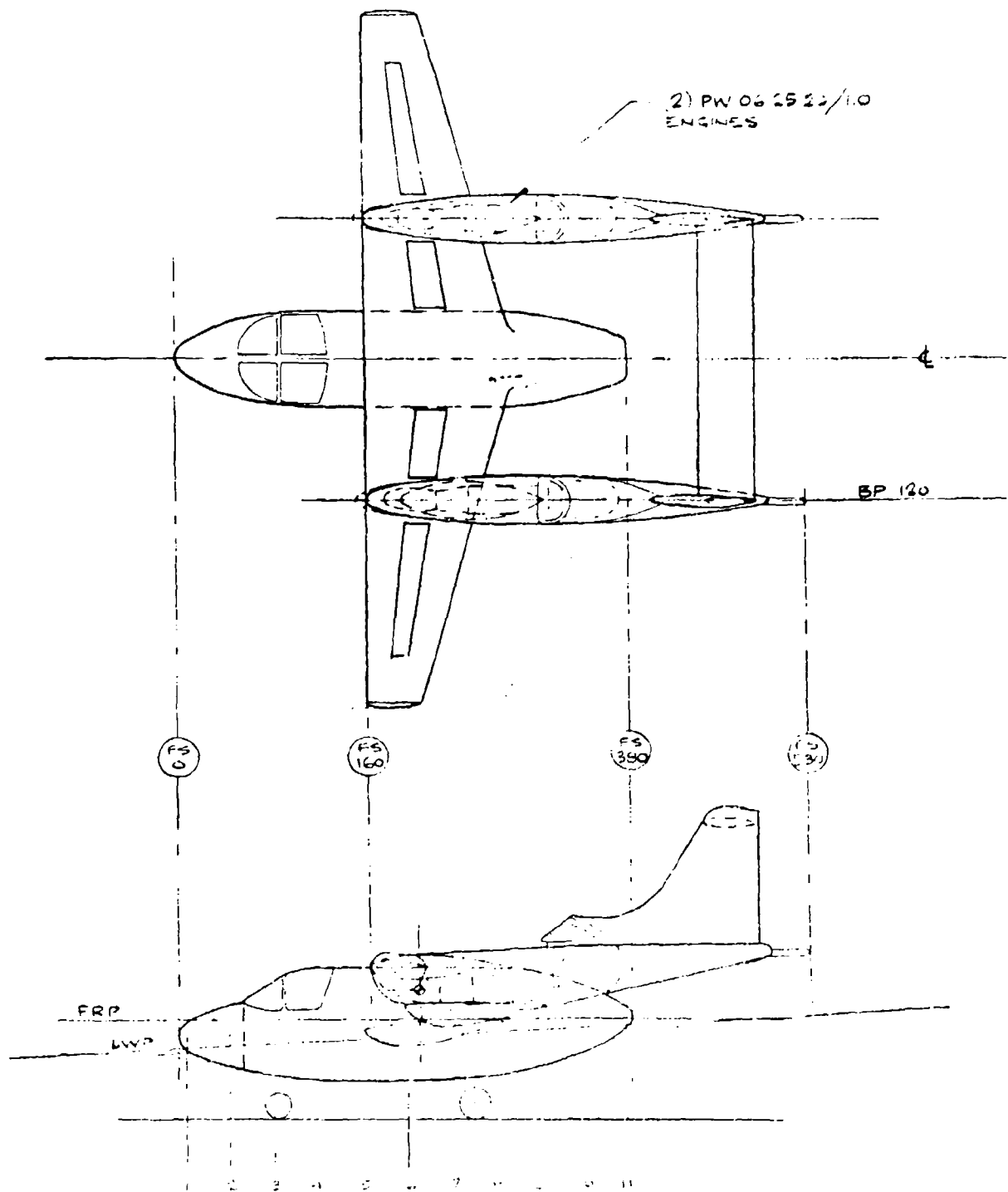
TCGW 25000 LBS  
 SPAN 600 IN  
 LENGTH (OVERALL) 530 IN

DATA FOR SEAKEEPING PROGRAM

NO OF STATIONS 11.0  
 LENGTH 370.0 IN (30.83 FT)  
 BEAM 80.0 IN (6.67 FT)  
 DRAFT 37.0 IN (3.08 FT)  
 YCG - 7.1 IN (-.582 FT)  
 ZCG - 40.0 IN (-3.33 FT)  
 KYC 121.4 IN (10.12 FT)  
 COCKPIT LOCATION { 115.0 IN FWD OF J  
 30.0 IN FREEBOARD

STN NO	BEAM (IN)	DRAFT (IN)	SECTIONAL AREA (IN <sup>2</sup> )	DIST. BTWN STNS (IN)
1	0	0	0	STNS SPACED 37 IN APART
2	60	17	714	
3	73	25	1625	
4	80	31	2294	
5	80	35	2590	
6	80	37	2738	
7	80	39	2896	
8	80	36	2664	
9	77	31	2201	
10	62	20	840	
11	0	0	0	





6



NR 76H-137

WING  
 $S_w$  350 FT<sup>2</sup>  
 $R$  7.2  
 $\lambda$  0.35  
 $\frac{1}{LE}$  0°  
 $\frac{1}{c}$  18% SC

HORIZONTAL TAIL  
 $S_H$  69 FT<sup>2</sup>  
 $R$  4.87  
 $\lambda$  1.0  
 $\frac{1}{LE}$  0°  
 $\frac{1}{c}$  15.5%

AUGMENTER (EA PANEL)  
 $A_2$  2910 IN<sup>2</sup>  
 $A_0$  194 IN<sup>2</sup>  
 $A_2/A_0$  15  
 $L/d$  1.5  
 $\phi$  1.65

VERTICAL TAIL  
 $S_V(EA)$  59 FT<sup>2</sup>  
 $R$  1.56  
 $\lambda$  0.28  
 $\frac{1}{LE}$  30°  
 $\frac{1}{c}$  10.5

2) PW 06 2520/1.0  
 ENGINES

BP 120

COPY AVAILABLE TO DDC DOES NOT  
 PERMIT FULLY LEGIBLE PRODUCTION

FIGURE 6

CONFIGURATION 6

1801-010

VISUAL SEARCHED AIRCRAFT

PROPULSION WING, TWIN ENGINE  
 2800 LBS TOGW

SCALE 1/100

2. INCHES 10.00 2.00



Columbus Aircraft Division  
Rockwell International  
NR76H-137

5 and 6 indicate that as configurations are scaled down in weight from 40,000 lb TOGW to 25,000 lb TOGW, the moment of inertia decreases from 95,000 slug-ft<sup>2</sup> to 80,000 slug-ft<sup>2</sup> and Kyy increases from 8.7' to 10.12. Here, weight is decreasing faster than the moment of inertia with a consequent increase in radius of gyration.

Note also that the pitch radius of gyration of Configuration 4, the X-wing is taken at the same value of Configuration 6, the twin boom fixed wing aircraft. These values were estimated based on inputs from manufacturers of single rotor helicopters to be comparable (in pitch) to that of fixed wing aircraft.



Columbus Aircraft Division  
Rockwell International  
NR76H-137

#### 4.0 HEAD SEAS ON WATER MOTION ANALYSIS

The head seas on-water motion analysis consisted of determining the sea keeping parameters of six different configurations (sectional area and water plane area distributions, center of buoyancy, metacentric height, etc.) and performing a regular waves, head seas computerized analysis of heave, pitch, acceleration (of the cockpit and c.g.) and cockpit wetness. The computerized analysis was based on the computer program described in Reference 2. The computer program provides predicted seakeeping behavior in regular waves and in a seaway (irregular waves). The initial form of the computer program was presented in 1969 by Dr. Robert Beck (see Reference 3).

Table 2 summarizes the physical characteristics that most directly influence seakeeping performance for the six configurations under consideration. Both model and full scale (F.S.) data is provided on configuration No. 3, the David Taylor-Naval Ship Research and Development Center (DT-NSRDC) design. All terms are defined in Section 7.0, Definitions.

Acceptable on-water motions are primarily influenced by the following parameters:

- (i)  $\frac{K_{yy}}{L}$  the ratio of the radius of gyration to the water line length of the hull or float. A value of  $\leq .25$  is desirable for acceptable pitch motion.
- (2)  $L$  the waterline length. The longer the waterline length, the less the craft is influenced by short length waves. As the sea state increases, even long craft (e.g. 200 feet in length) are influenced and eventually these craft will contour the waves too. Super tankers and large ships of course don't contour the waves. Extreme bending moments must be counteracted if the craft does not follow the wave contour. This bending moment is proportional to the wave height associated to the wave length that equals the waterline length of the craft (see Appendix 1).
- (3)  $\overline{GM}$  the metacentric height. A positive  $\overline{GM}$  is required for inherent static stability. Roll is most critical ( $\overline{GM}_R$ ). Configurations 3 through 6 are all unstable in roll without wing tip floats. Configuration 4 has no roll static stability and is dependent on an active roll control device. The metacentric height in roll,  $\overline{GM}_R$ , shown in Table 2 is for the hull only.



Columbus Aircraft Division  
Rockwell International  
NR76H-137

Of particular interest to head seas pitching motion is the relationship of the radius of gyration in pitch,  $K_{yy}$  to the waterline length,  $L$  (see last row of Table 5). Configurations 2 through 5 all have a ratio of  $K_{yy}/L$  of .22 to .24. Configuration 6, the 25,000 lb V/STOL twin boom has a  $K_{yy}/L$  ratio of .33. Configuration 1, the 1.25 M lb CTOL Catamaran has a  $K_{yy}/L$  ratio of .49, considered unacceptable for good head seas pitch motions. A good value of  $K_{yy}/L$  is considered to be .25. The combination of high radius of gyration (high mass inertia), high c.g. and short float length (120 feet) and limited beam (12 feet) for configuration 1, result in a poor combination of design characteristics for head seas pitch motion (see Section 5.0). A doubling of float length and water plane area for configuration 1 would decrease  $K_{yy}/L$  to .25. This change is considered necessary to provide acceptable pitch motions in head seas for configuration 1.

The predicted heave, pitch and acceleration motions of the six study configurations are shown in Figures 7, 8 and 9. The actual characteristics of these configurations as run on the computer varied somewhat from design conditions. These characteristics are shown in Table 6 for reference. Significant differences are discussed in the following pages. The heave motions at the c.g. (Figure 7) are almost identical for all comparable weight craft. Configurations 3 through 6 are comparable in weight, heave frequency and length and the heave motions are very similar. They represent "pure wave following concepts" where the significant heave is equal to the significant wave height for all sea states.

For reference, a FF 1040 (DE 1040) of 2620 tons (5.24M lbs) and 414.5 ft length at 20 knots heave curve is shown. As indicated, heave is reduced in proportion to the length of the craft as weight increases.

Figure 8 shows significant pitch at head seas for all six study configurations at zero and 5 knots forward speed. Configuration 2 has the best pitch characteristics and configurations 1 and 6 the worst. Configurations 3, 4 and 5 show curves of significant pitch vs significant wave height that are very typical of wave following concepts. The RMS wave slope is about 6 to 7 degrees from sea states 6 to 7 (see Appendix 1). For reference, a curve of significant pitch for a DE 1040 is also shown.

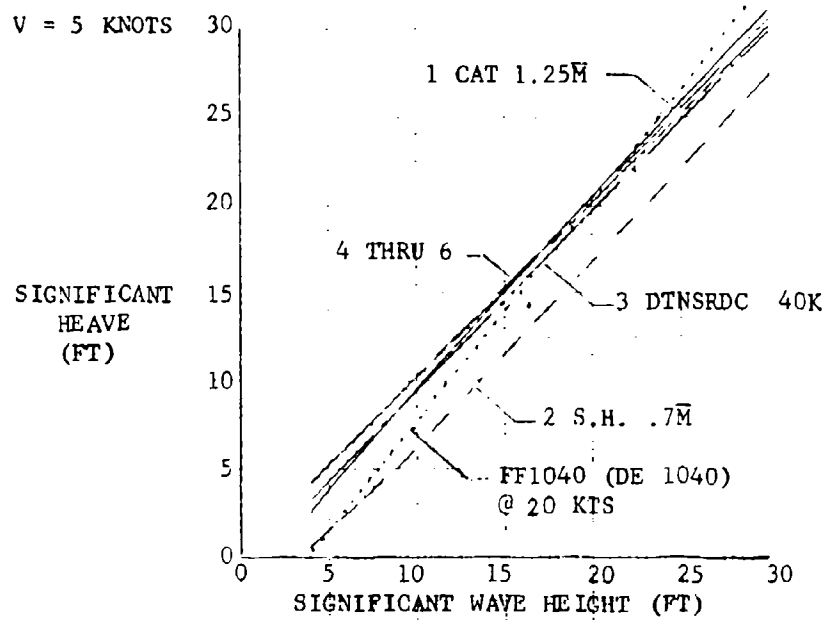
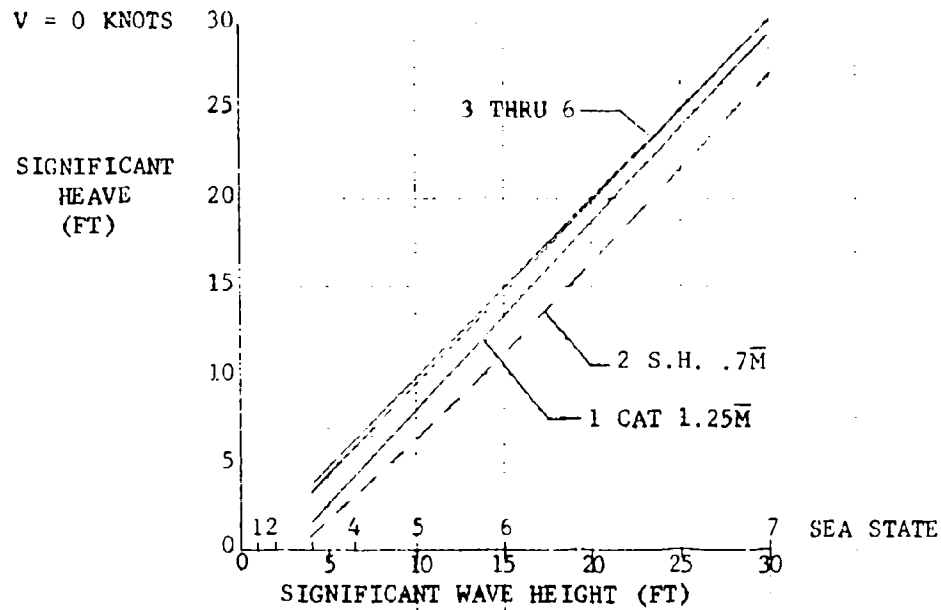


Figure 7. Significant Heave - Head Seas

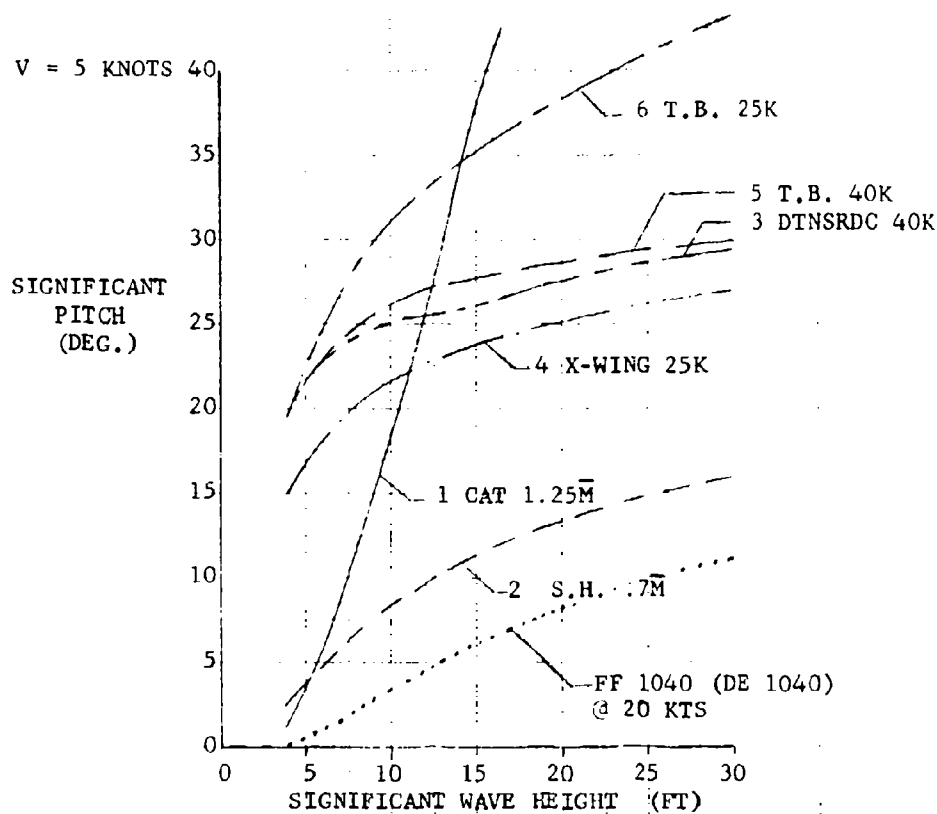
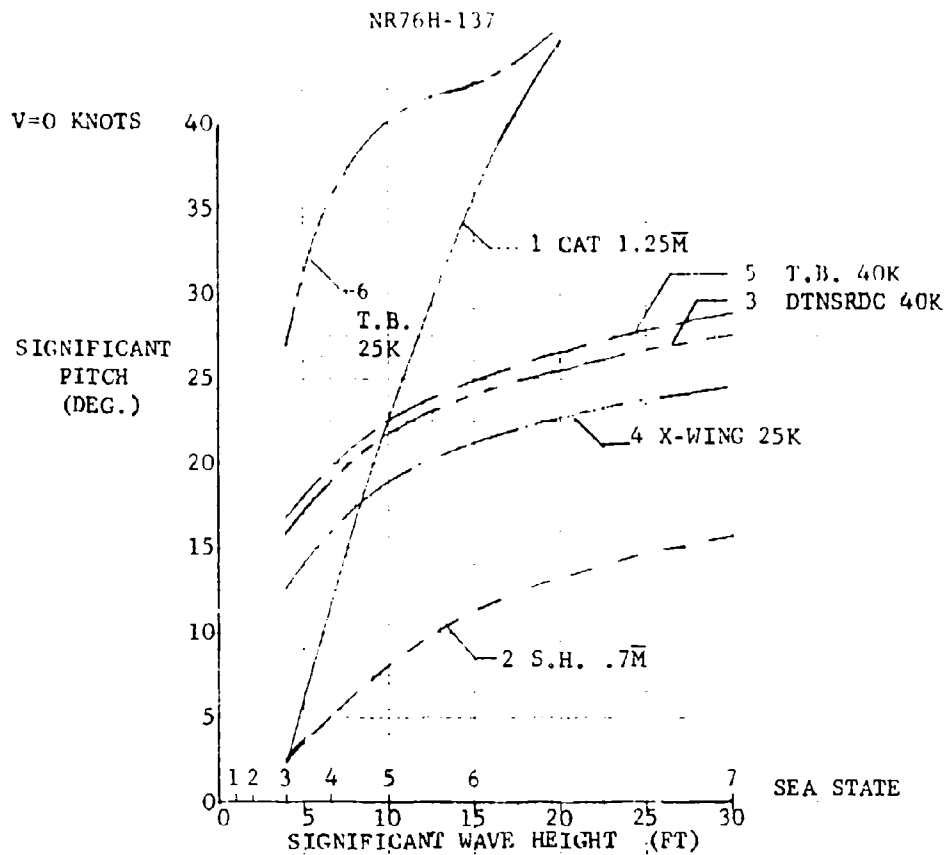


Figure 8. Significant Pitch - Head Seas

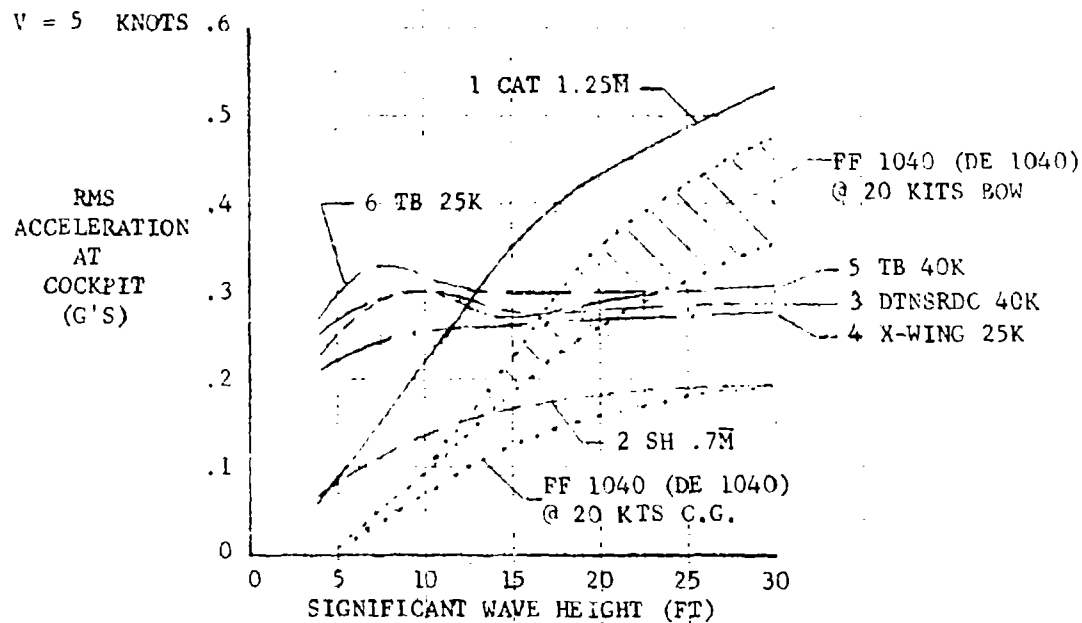
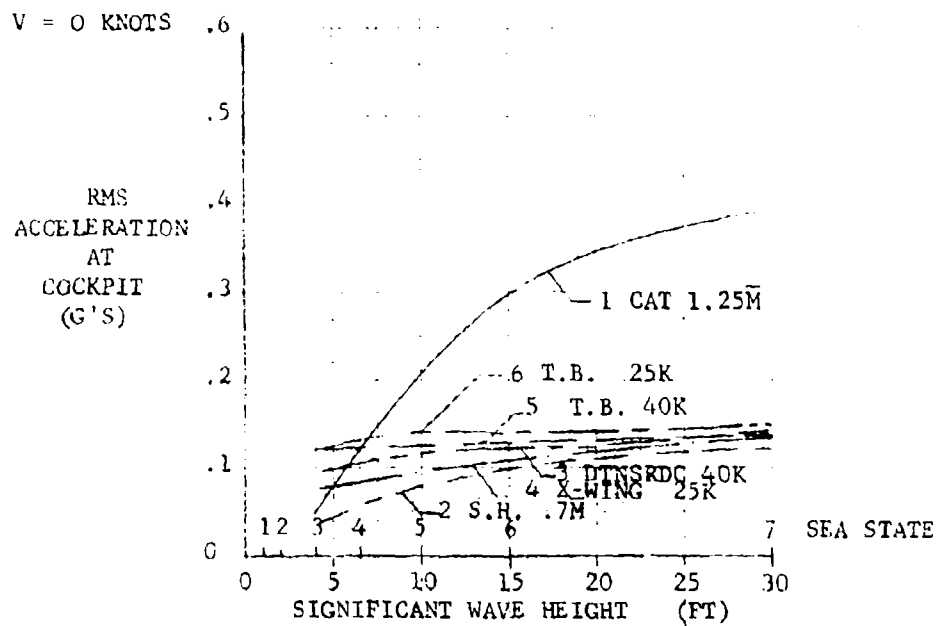


Figure 9. RMS Acceleration at Cockpit - Head Seas



Columbus Aircraft Division  
Rockwell International  
NR76H-137

Figure 9 is the RMS acceleration motions of the cockpit locations in g's for the study configurations at zero and 5 knots forward speed. Configuration 2 has the lowest accelerations for all sea states of the configurations studied. This is due to its size and length. Except for configurations 1 and 2, all configurations fall in a band of about .1 to .15 RMS g's at  $V = 0$  and .25 to .30 g's RMS at  $V = 5$  knots. As will be shown subsequently, proper configuration design can provide a head seas RMS acceleration of .1 g's at  $V = 0$  knots and .2 to .24 RMS g's at  $V = 5$  knots independent of sea state in the surface following mode. This is for a craft length of 40 to 45 feet. Craft size does not appreciably decrease RMS g's at the cockpit at zero speed except at very low sea states.

The g's shown here are for the cockpit station locations of the respective craft. The actual crew station locations during on water operations would be more centrally located and reflect the g levels close to the center of gravity (C.G.). The g's at the C.G. are all below 0.10 RMS at zero speed for all sea states (see Figure 10). Depending on craft length and damping RMS g's at the C.G. can be as low as .05. For reference, the wave surface g's are shown in Figure 10 at zero speed and approach .125 g's RMS at the higher sea states.\*

This wave surface g curve shown represents the g's of a very small craft (e.g. lifeboat) would receive while riding on the wave surface. The craft shown have lower RMS g levels due to damping and craft size.

On-water speed has a greater effect in increasing g level than any other parameter. Compared with zero speed, five knots more than doubles the g's encountered. For example, for the DT-NSRDC model at four foot significant wave height (Sea State 3), the RMS g's jump from .1 to .265. Bow shaping may in part reduce these g's, but not appreciably. Speed is considered to be the primary contributor. Again, g's at the C.G. are lower than the cockpit g's at 5 knots and are more acceptable for crew operations.

For reference, accelerations at the C.G. and bow for an FF 1040 (DE 1040) in head seas at 20 knots is shown (see Figure 9,  $V = 5$  knots).

\* At very low sea states (below 3) wave surface g's actually increase considerably over the values shown in Figure 10. These g levels do not represent craft motion g's and were not shown.



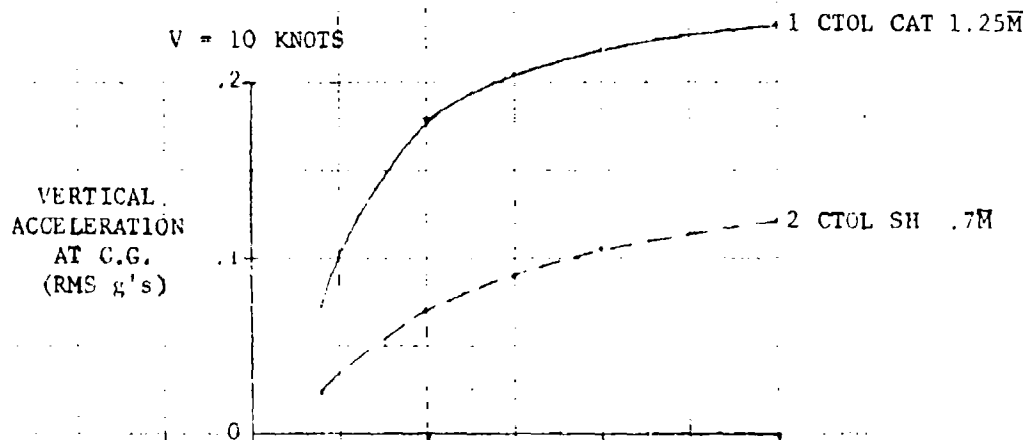
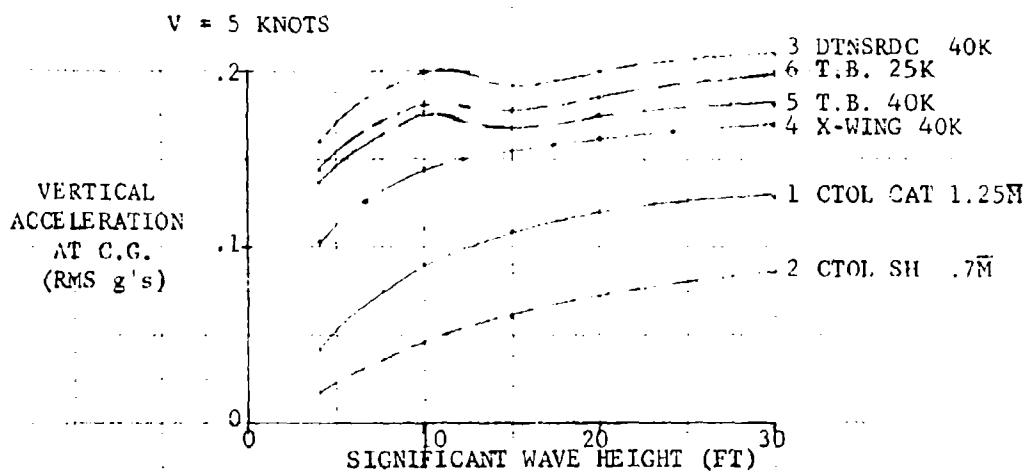
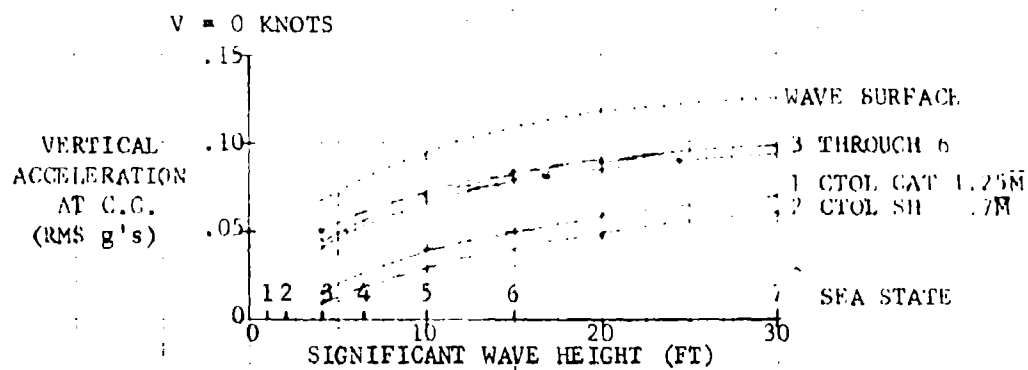


FIGURE 10. RMS VERTICAL ACCELERATION AT C.G. - HEAD SEAS



Columbus Aircraft Division  
Rockwell International  
NR76H-137

Table 2. Head Seas On-Water Motion and Stability Data

Configuration	1	2	3	4	5	6	7 (F.S.)
Parameter	Catamaran	CatOL Single Hull	CatOL DT-NSRDC Model	VtOL X-Wing	VtOL Twin Boom	VtOL 4-in Boom	C/STOL DT/NSRDC Full Scale
W or $\Delta$ (lbs)	1.25 H	.769 H	330	25 R	40 R	25 R	41.25 R
L/B/T (ft)	120/12/9.75	170.4/25/7.12	7.38/1.58/.8	43/6.25/2.5	39.2/7.3/3.5	30.8/6.7/3.1	36.9/7.9/4.0
$\Delta W / V$ (ft <sup>2</sup> )	2700/19,531	3920/12,016	10.6/5.16	260.4/391	244.4/625	175/391	265/645
$Z_{CG}/Z_{CB}$ (ft)	-20/3.93	-7/3	-.34/.25	-.92/3.2	-1.44/3.33	-1.25/3.33	-1.45/1.25
$C_b$	.798	.344	.559	.581	.622	.617	.559
Float Half Span (ft)	21	107.5	4.8	0	12.4	10.0	24.0
$I_{XX}/I_{YY}$ (Slug-ft <sup>2</sup> )	$\frac{1.33 \times 10^8}{1.23 \times 10^8}$	$\frac{.36 \times 10^8}{.32 \times 10^8}$	32.0/29.5	80,000/30,000	95,000/85,000	80,000/70,000	70,000/56,440
KY/KX (ft)	58.6/56.2	38.8/36.6	1.76/1.66	10.12/6.20	8.74/8.77	10.12/6.20	8.84/8.34
$L_{AY}/L_{AX}$ (ft <sup>4</sup> )	$2 \times 10^6 / 1.2 \times 10^6$	$8 \times 10^6 / 2 \times 10^6$	39.8/2.21	37,685/848	24,840/998	11,280/580	27,562/1242
$C_{TP}/C_{SR}$ (ft)	121.9/38.6	655.8/6.98	7.4/-1.2	92.4/-1.92	35.0/-3.17	24.3/-3.10	40.0/-0.80
KY/L	.49	.23	.24	.235	.223	.329	.24



Columbus Aircraft Division  
Rockwell International  
NR76H-137

Table 3. Analyzed Configuration Characteristics

Configuration Parameter	1 CTOL CATAMARAN	2 CTOL SINGLE HULL	3 C/STOL DT-NSRDC FULL SCALE	4 VTOL X-WING	5 V/STOL TWIN BOOM	6 V/STOL TWIN BOOM
W or $\Delta$ (lbs)	1,244,230	771,343	42,505	24,655	40,728	25,638
L (ft)	120	170	36.87	43.0	39.17	30.83
B (ft)	12	25	8.0	6.25	7.33	6.67
T (ft)	9.75	7.12	4.0	2.5	3.5	3.08
K <sub>YY</sub> (ft)	66.93	38.82	8.79	10.15	8.74	10.12
X <sub>CG</sub> (ft)	-2.85	2.67	.5633	.22	-.62	2.57
Z <sub>CG</sub> (ft)	-20	-7	-1.25	-3.16	-3.33	-3.33
L/B	10	6.8	4.62	6.88	5.34	4.63
$\frac{K_{YY}}{L}$	.557	.23	.238	.236	.222	.328



Columbus Aircraft Division  
Rockwell International  
NR76H-137

## 5.0 DESIGN PARAMETER VARIATION EFFECT

### 5.1 Configuration 1, CTOL Catamaran, 1.25M Lb. TOGW

The motions for Configuration 1 were found to be excessive (see Section 4.0). In addition, at zero speed, waves break over the cockpit at a significant wave height of 13 feet, 100 times per hour. Higher wave heights are even worse.

Design modifications were considered to improve longitudinal damping, resultant pitch motion, and acceleration. Alternatives to Configuration 1, 1-A, 1-B, and 1-C, are described in Table 4. Configuration 1-A reduced the radius of gyration by a factor of about 2 and reduced the CG height by a factor of two. Configuration 1-B increased the length from 120 feet to 150 feet. The heave, pitch, and roll of Configurations 1, 1-A and 1-B are shown in Figures 11, 12, and 13. While the pitch motions were improved for Configuration 1-A over Configuration 1, Configuration 1 was still best from an RMS g's standpoint (see Figure 13). This is because of the phasing of pitch and heave. Pitch and heave are higher for Configuration 1 than for 1-A or 1-B but more out of phase (see Appendix 2 for reference to the Response Amplitude Operators, RAO's).

Configuration 1-C, with a doubling of float length and water plane area, is recommended to correct the adverse motions of this catamaran design. If doubling the length by itself does not result in acceptable motion accelerations, increasing float beam and the addition of pitch damping devices (foils fore and aft) may also be required.

Table 4. Configuration 1 Alternatives Analyzed

Parameter	Alternative	1	1-A	1-B	1-C
		CTOL Catamaran	CTOL Catamaran	CTOL Catamaran	CTOL Catamaran
W or $\Delta$	(lbs)	1,244,230	1,244,230	1,244,230	1,244,230
L	(ft)	120	120	150	240
B	(ft)	12	12	12	12
T	(ft)	9.75	9.75	7.8	4.88
K <sub>yy</sub>	(ft)	66.93	30.	66.93	58.6
X <sub>cg</sub>	(ft)	-2.85	-2.85	-3.56	
Z <sub>cg</sub>	(ft)	-20	-10	-20	-20
$\frac{K_{yy}}{L}$		0.557	0.25	0.446	0.244
GM <sub>p</sub>	(ft)	121.9	121.9	257.0	1138

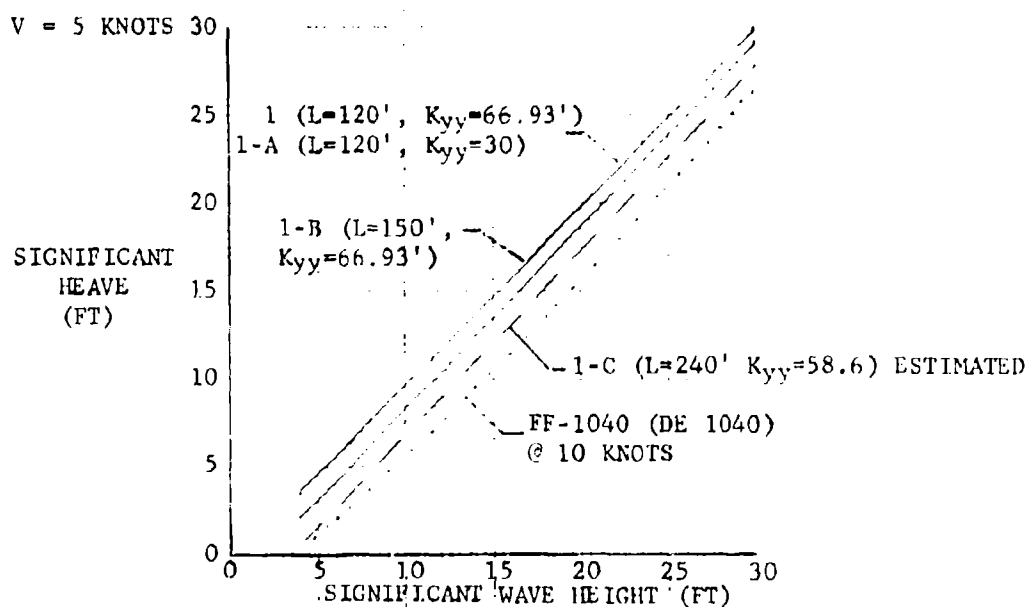
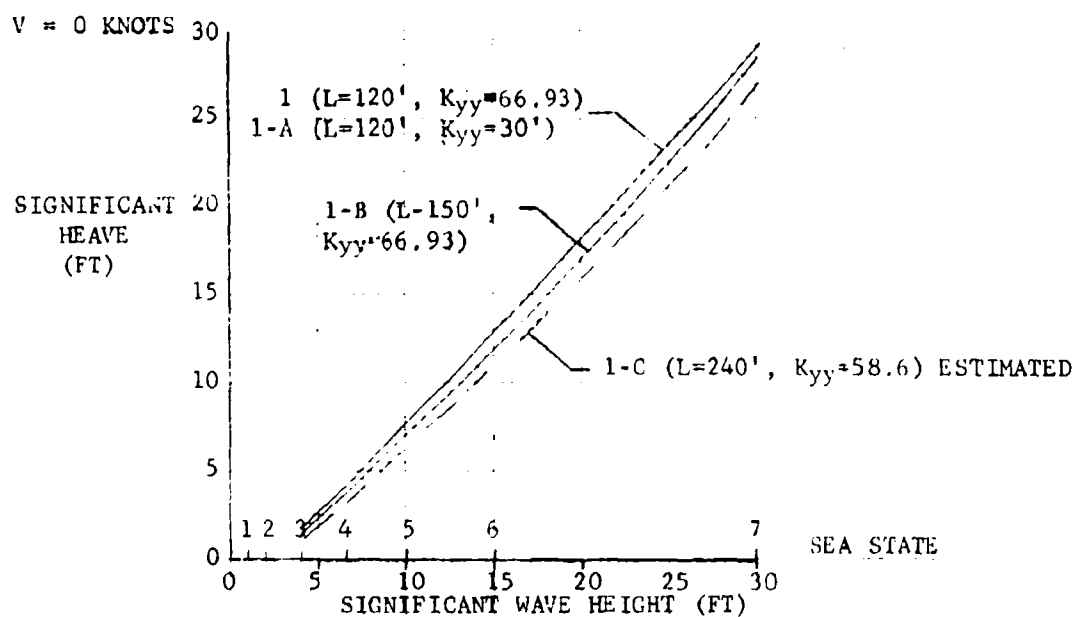


Figure 11. Significant Heave - Configuration 1 CTOL Catamaran Alternatives

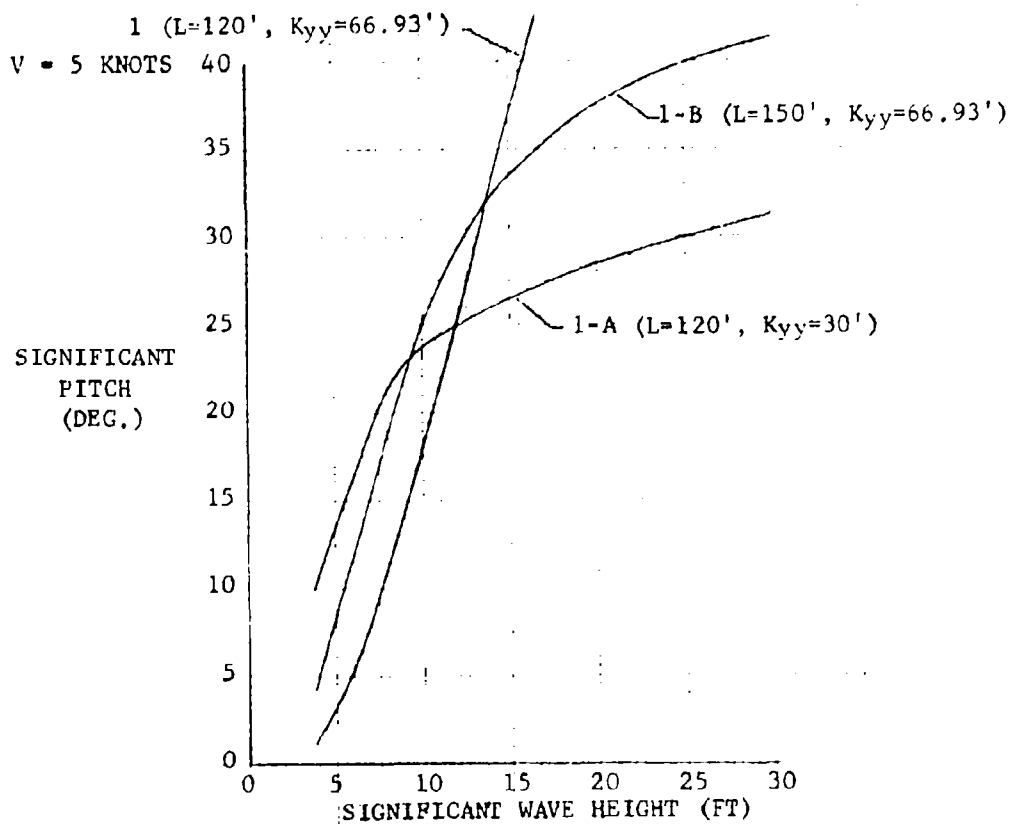
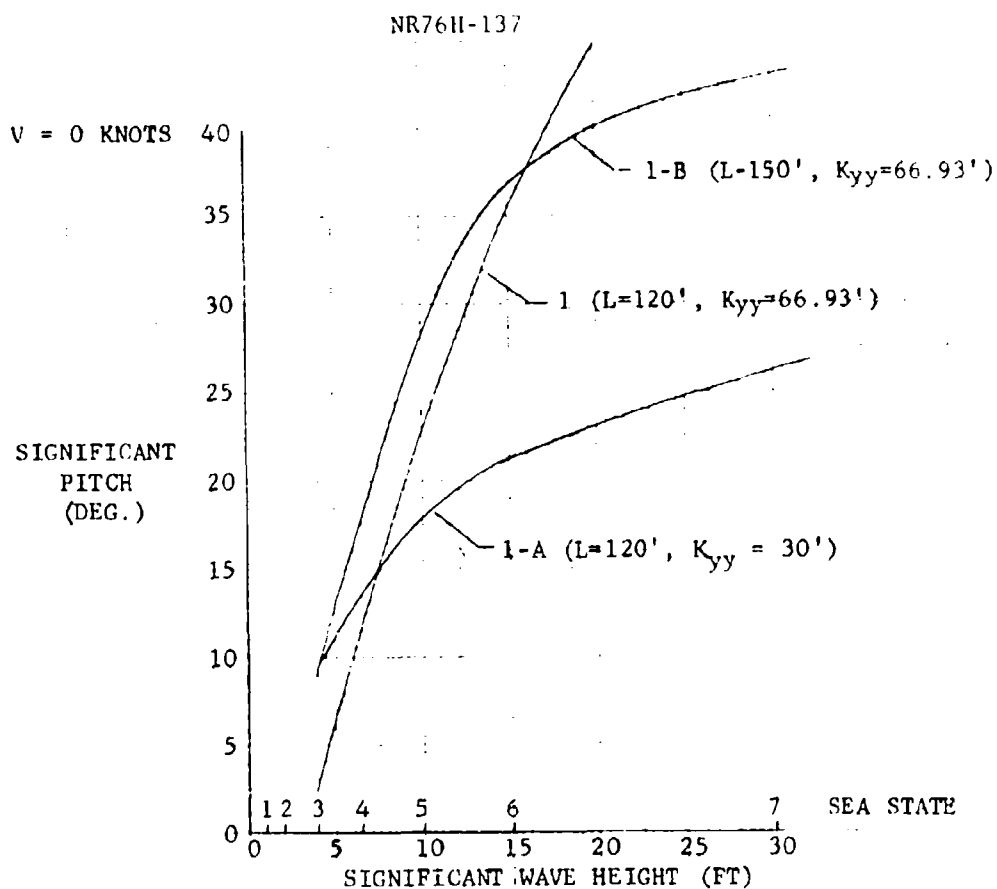


Figure 12 Significant Pitch - Configuration 1, CTOL Catamaran Alternatives

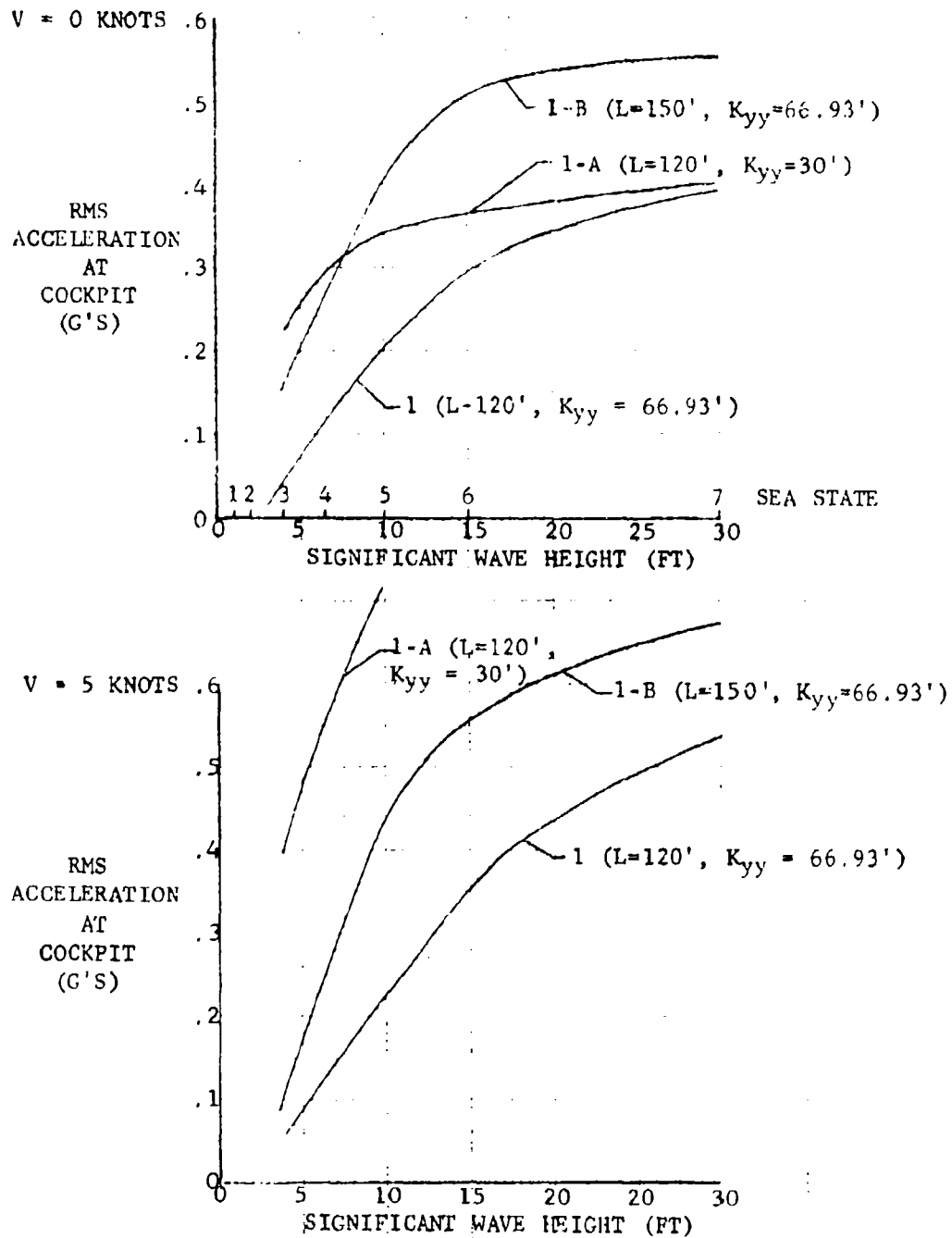


Figure 13. RMS Acceleration at Cockpit - Configuration 1, CTOL Catamaran Alternatives



## 5.2 Other Sea Based Aircraft Designs

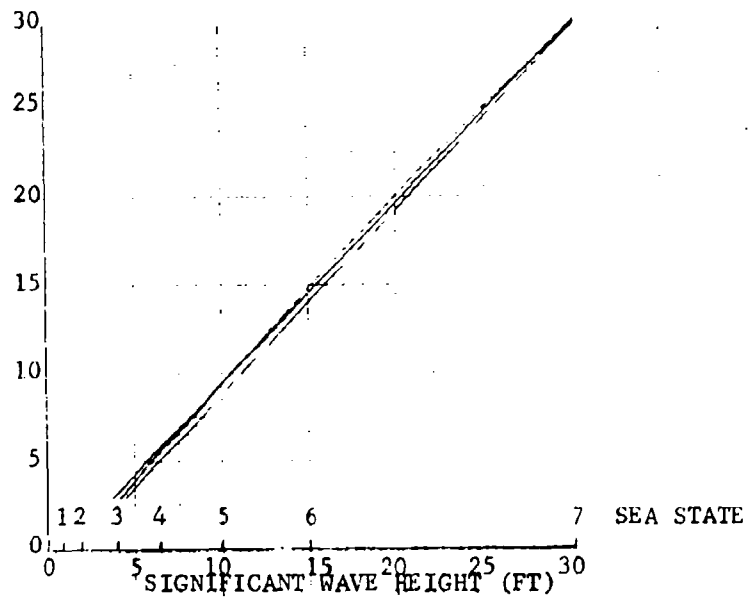
As a part of the Contractor's prior studies, other sea based aircraft designs were analyzed. Because of their significance, they are included here. Two catamaran and three single hull designs were studied (see Table 9 and Figures 14, 15 and 16). This analysis illustrates the same trends found in Section 4.0; particularly Figures 7, 8, and 9, for surface following aircraft in head seas; namely:

- 1) Heave is directly proportional to (and about equal to) wave height (see Figures 7 and 14). This indicates that the craft are contouring the waves for these sea states.
- 2) Pitch is proportional to inertia and CG height and inversely proportional to length and depends on shaping (damping). For all configurations with low values of  $K_{yy}/L$  ( $K_{yy}/L \leq .25$ ), a limit of about 20 to 30 degrees significant pitch (about 5 to 7.5 degrees RMS pitch) is obtained at zero speed (see Figures 8 and 15). For higher values of  $K_{yy}/L$  (.33 to .50), pitch angles can be extreme. This is readily apparent in Figure 8 where Configurations 3, 4, and 5 have a  $K_{yy}/L$  of about .24, Configuration 6 has a  $K_{yy}/L$  of .33, and Configuration 1 has a  $K_{yy}/L$  of .50. This conclusion does not apply to relative large craft or ships. Configuration 2 has the lowest pitch of all aircraft and the FF 1040 (DE 1040) has even less.
- 3) Low on-water speed and proper craft characteristics can assure a low RMS head seas acceleration, even at the cockpit of the craft. This conclusion is independent of sea state. This can be seen in Figure 9 and Figure 16 for  $V=0$  Knots. Zero speed, head seas acceleration levels of about 0.10 are obtained for the sea based craft of Table 5 and from 0.10 to 0.15 for all of the aircraft investigated in the study (except the 1.25M pound catamaran). This appears to be primarily influenced by (a)  $K_{yy}/L$  (at all sea states), and (b) length (more so at the lower sea states). As speed increases, these effects become more pronounced. The craft of Table 8 have slightly lower accelerations than those considered in the study. The major differences are because of lower  $K_{yy}/L$  (pitch inertia divided by length).

Figure 17 summarizes this conclusion for three representative craft and shows the effect of variation of  $K_{yy}/L$ . All craft have very similar accelerations at zero speed with the .7M single hull somewhat better at the low sea states. At 5 knots for the 40,000 pound configuration and at 10 knots for the .7M single hull the accelerations are all above .2 g's RMS at significant wave heights above 10 feet. Only at low sea states (below SS 5) does the 170 foot lengths .7M S.H. configuration have lower accelerations (i.e. only at low sea states and low speed does length improve the ride).



V = 0 KNOTS

SIGNIFICANT  
HEAVE  
(FT.)

V = 5 KNOTS

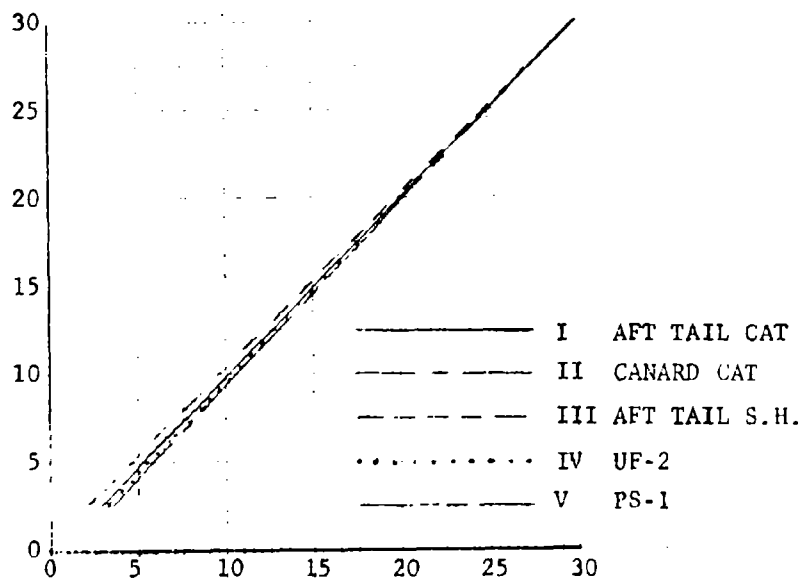
SIGNIFICANT  
HEAVE  
(FT.)

Figure 14. Significant Heave - Other Sea Based Aircraft Designs

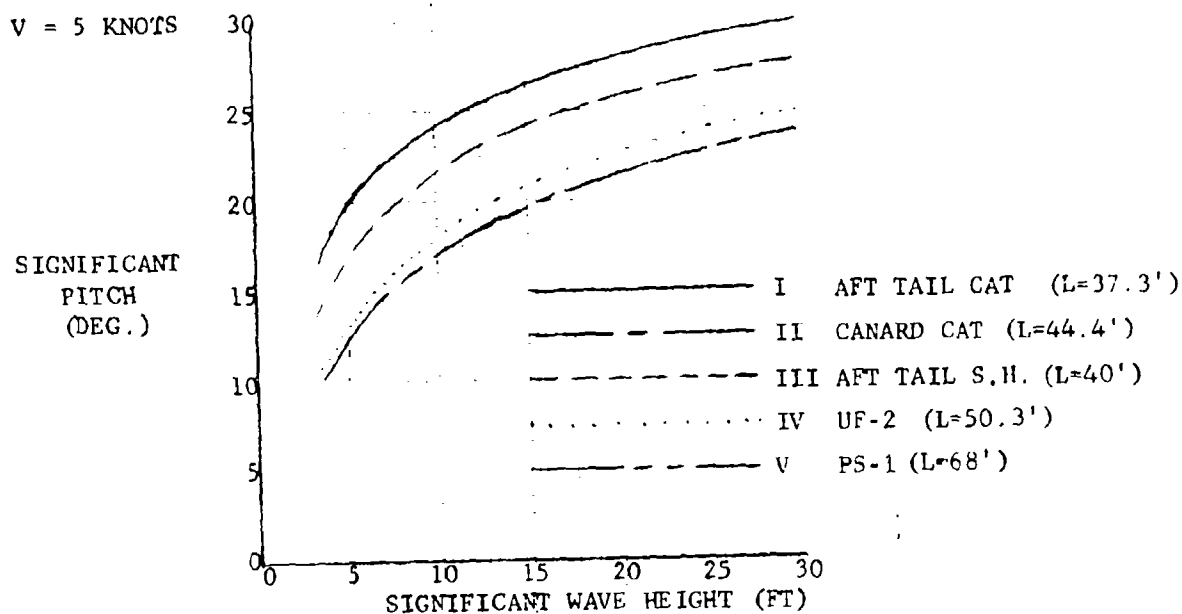
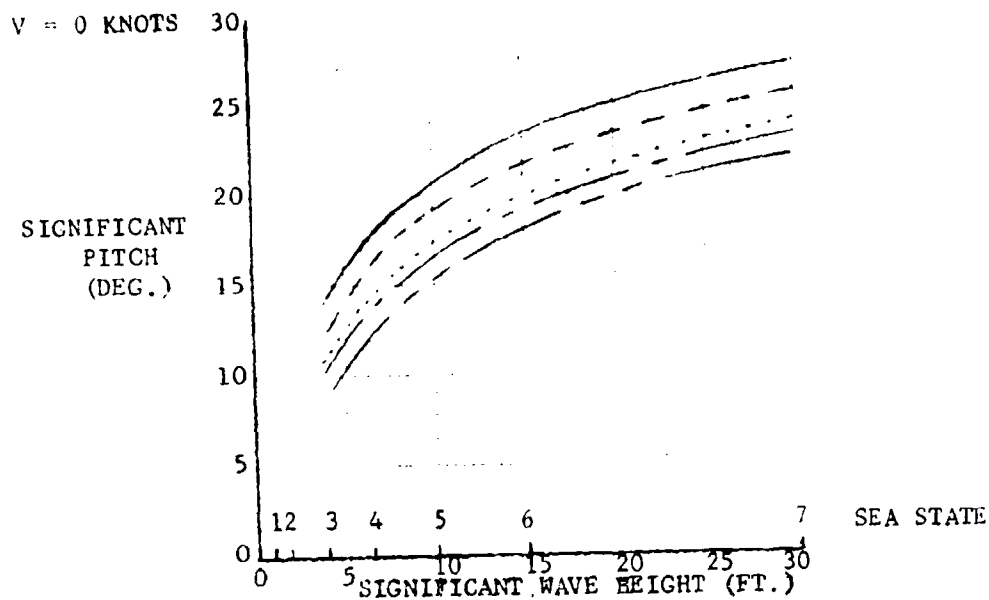
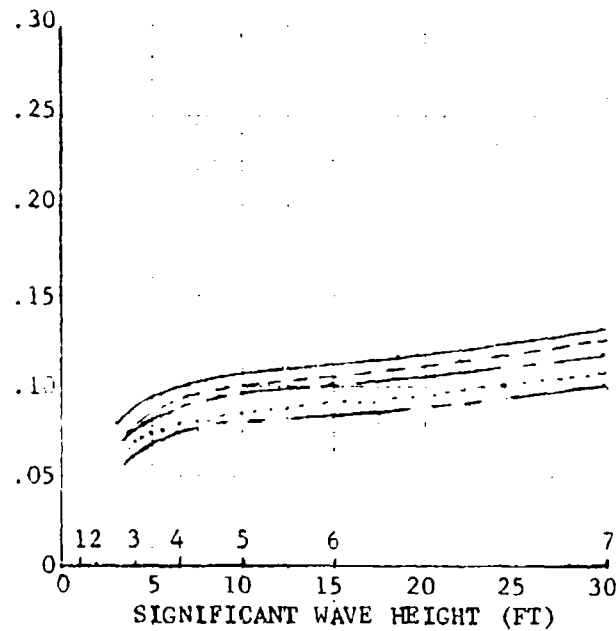


Figure 13. Significant Pitch - Other Sea Based Aircraft Designs

V = 0 KNOTS

RMS  
ACCELERATION  
AT  
COCKPIT  
(G'S)

V = 5 KNOTS

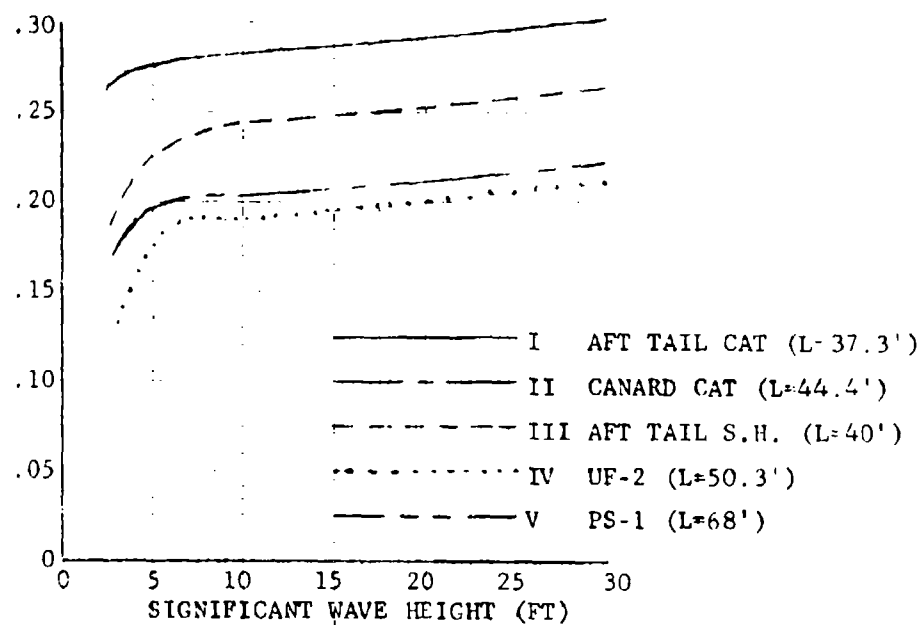
RMS  
ACCELERATION  
AT  
COCKPIT  
(G'S)

Figure 16. RMS Acceleration - Other Sea Based Aircraft Designs



Columbus Aircraft Division  
Rockwell International  
NR76H-137

Table 5. Other Sea Based Aircraft Designs Characteristics

Configuration Parameter	I Conventional Aft Tail Catamaran	II Canard Catamaran	III Conventional Aft Tail Single Hull	IV UF-2	V PS-1
W or $\Delta$ (lbs)	40K	40K	40K	80K	86K
L (ft)	37.34	44.4	40.4	50.34	68.0
B (ft)	4	4	7		
T (ft)	3	3	3.75		
K <sub>yy</sub> (ft)	5.3	5.33	5.28	6.65	
X <sub>cg</sub> (ft)					
Z <sub>cg</sub> (ft)	-4.48	-1.066	-3.48	5.64	
$\frac{K_{yy}}{L}$	.142	.12	.132	.132	

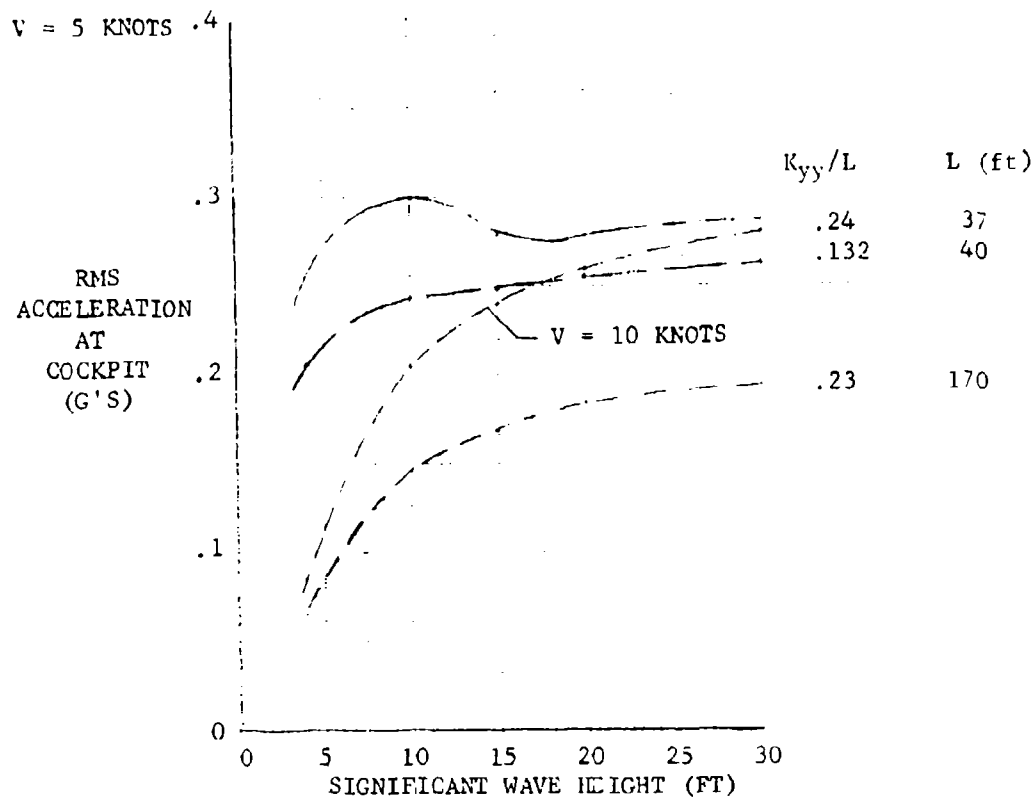
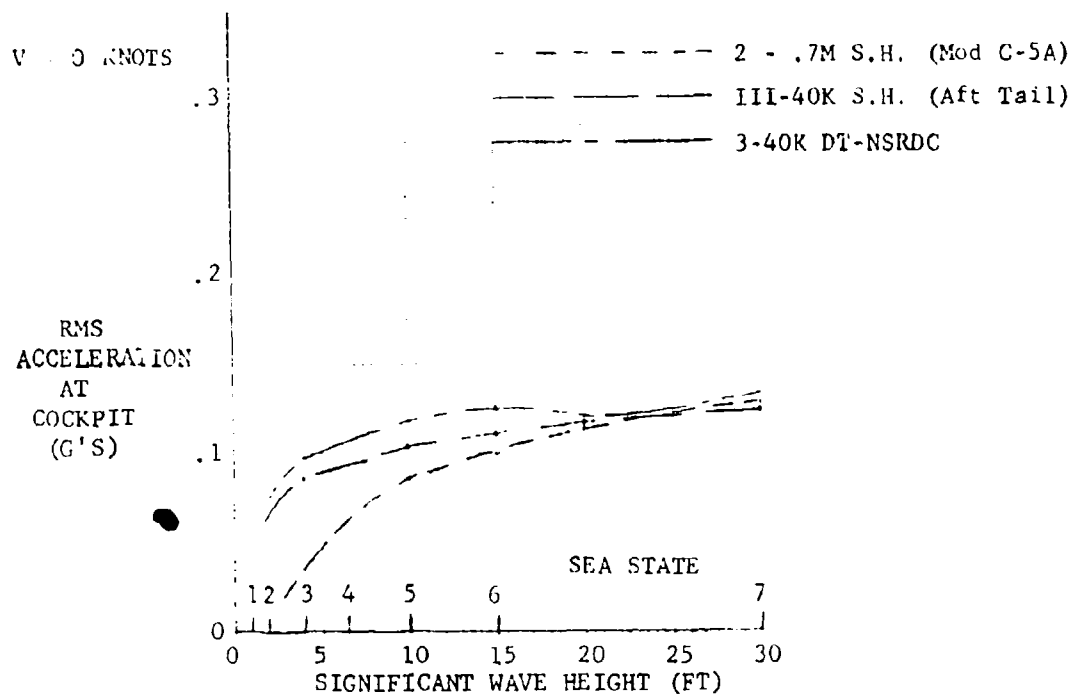


Figure 17. Head Seas - RMS Accelerations at Cockpit of Different Concepts



Columbus Aircraft Division  
Rockwell International  
NR76H-137

## 6.0 MODEL TANK TEST PROGRAM RECOMMENDATIONS

Based on the results of this study, the following recommendations are made for subsequent model tank testing:

- 1) Extension of analytical study results - This study needs to be extended to precisely define desired configuration characteristics for sea based aircraft design. Variations in  $K_{yy}/L$  and  $L/b$  at head, beam, and quartering sea conditions establishing the RMS accelerations for representative sea based aircraft (40-50 foot, 40,000 pound and 30-40 foot 25,000 pound TOGW) are indicated. Since the designs considered had normal aerodynamic fineness ratios (length to beam of 4-6) and provided good motions and accelerations on the water at zero speed, high length to beam ratio designs are not required for improved on water motion and normal aerodynamic designs do provide good on water motion characteristics. These conclusions, if verified, place increased emphasis on VTOL technology concepts for sea basing. Extreme hull shaping penalties (high  $L/B$  ratios, vertical floats, damping devices) are not required for acceptable on water motion. Since lower  $L/B$  hull ratios have higher landing impact  $g$ 's at the same landing speed, lower landing speeds are indicated to keep landing loads at the same level or lower than flight loads. Pure VTOL technology can provide this capability and also save in configuration weight by avoiding hull weight penalties needed for increased impact landings, dead rise, steps, flares, chines, etc., required for CTOL and STOL water operation. Cruise performance advantages through good clean aerodynamic design configurations are also achieved.

Analytical studies of beam sea and quartering sea conditions should accompany the model testing.

- 2) Water takeoff and landing tests need to be performed to establish control limits, design limits and desired configuration features (hull, float shape, engine inlet/exhaust locations) for high sea state operation.
- 3) Propulsion system/configuration alternatives that provide positive lift in the proximity to the water surface need to be established.

Alternative configurations that feature positive "in surface effect" lift such as RAM wing, underwing/nacelle surfaces or other lifting features should be emphasized.



Columbus Aircraft Division  
Rockwell International  
NR76H-137

Propulsion-lift system features that minimize salt water spray ingestion must be emphasized. Advanced technology (low Q, high augmentation) systems are indicated. The ability to control the direction of spray may be the best means of avoiding salt spray ingestion. Propulsion-lift systems with this capability should be investigated.



Columbus Aircraft Division  
Rockwell International

NR76H-137

7.0 DEFINITIONS

7.1 WAVE PARAMETERS

$\eta_m$  is wave amplitude  $\eta_m = \frac{1}{2} h$  (h = wave height)

$\beta$  is phase angle

k is wave number  $k = \frac{2\pi}{\lambda} = \frac{\omega^2}{g}$

$\lambda$  is wave length  $\lambda = \frac{T_w^2}{g} = \frac{2\pi c^2}{g} = \frac{2\pi g}{\omega^2}$

$\omega$  is wave frequency  $\omega = \frac{2\pi}{T_w} = \frac{T_w g}{\lambda}$

g is gravitational acceleration  $g = 32.2 \text{ FT/SEC}^2$

$\alpha$  is wave heading

t is time

$T_w$  is wave period

c is wave celerity  $c = \sqrt{\frac{g}{k}} = \frac{\lambda}{T_w} = \frac{g T_w}{2\pi} = \frac{g}{\omega}$

E is wave energy intensity  $E = \frac{1}{\lambda} \rho g \int \eta^2(x) dx$

For a full wave length:

$$E = \frac{1}{2} \rho g \eta_m^2 = \frac{1}{8} \rho g h^2$$

h is wave height  $h = 2 \eta_m$

$S\eta(\omega)$  is wave spectral density ( $\text{FT}^2\text{-SEC}$ )

$S\eta(\omega) = \alpha \omega^{-5} \exp(-\beta \omega^{-4})$  ( $\text{ft}^2 \times \text{sec}$ )

$\omega$  = circular frequency ( $\text{sec}^{-1}$ )

$\alpha = \frac{5}{16} \omega_p^4 (\bar{h}^{1/3})^2$  ( $\text{ft}^2/\text{sec}^4$ )

$\beta = \frac{5}{4} \omega_p^4$  ( $\text{sec}^4$ )

$\omega_p$  = spectral peak frequency





Columbus Aircraft Division  
Rockwell International

NR76H-137

For fully developed seaways according to Pierson and Moskowitz:

$$\alpha = 0.0081 g^2 \quad (\text{ft}^2/\text{sec}^4) \quad \text{and}$$

$$\beta = 0.0324 g^2/H^{1/3})^2 \quad (\text{sec}^4)$$

where

$$\omega_p = 0.4013 g^{1/2}/(H^{1/3})^{1/2} \quad (\text{sec}^{-1})$$

$$g = \text{acceleration in ft/sec}^2$$

$$h_s = \text{significant wave height (ft)}$$

$$h_s = 4.0 \left[ \int_0^\infty S_\eta(\omega) d\omega \right]^{1/2}$$

$$h_s = 4 \text{ times the RMS of the spectrum}$$

$$T_{av} = \text{average period of seaway}$$

For fully developed seaways

$$T_{av} = 1.96 (H^{-1/3})^{1/2} \quad (\text{sec})$$

$$\omega_e = \omega - \frac{\omega^2 V \cos \alpha}{g} = \omega (1 - \mu)$$

$$\omega_e = \text{apparent wave (exciting) frequency or frequency of wave encounter}$$

$$V = \text{speed of hull}$$

$$\alpha = \text{wave heading}$$

$$\mu = \frac{V \cos \alpha}{g}$$

## 7.2 HULL PARAMETERS

$$L \text{ is length (FT)}$$

$$B \text{ is beam (FT)}$$

$$T \text{ is draft (FT)}$$

$$\nabla \text{ is volume (FT}^3\text{)}$$

$$\Delta \text{ is displacement (weight) (lbs)} \quad \Delta = W = \rho g \nabla$$

$$\rho g = 64 \text{ LBS/FT}^3$$

$$C_b \text{ is block coefficient}$$

$$C_b = \frac{\nabla}{LBT}$$



Columbus Aircraft Division  
Rockwell International  
NR76H-137

$C_v$  is vertical coefficient  $C_v = \frac{V}{A_w T} = \frac{V}{C_w LBT}$

$A_{wp}$  is waterplane area

$C_w$  is waterplane coefficient  $C_w = \frac{V}{C_v LBT}$

$F_N$  is Froude number  $F_N = \frac{V}{\sqrt{gL}}$

$V$  is speed of hull

$\overline{GM}_i$  = metacentric height (ft) in mode i ( $z_i$ )  
(distance from G to M, metacentric center)

$\overline{GM}_p$  = metacentric height (ft) in pitch ( $z_\psi$ )

$\overline{GM}_R$  = metacentric height (ft) in roll ( $z_\theta$ )

$\overline{GM}_i = \overline{BM}_i - \overline{BG}$

$\overline{BM}_i$  = distance from center of buoyancy to metacentric center  
( $z_{ii}$ )

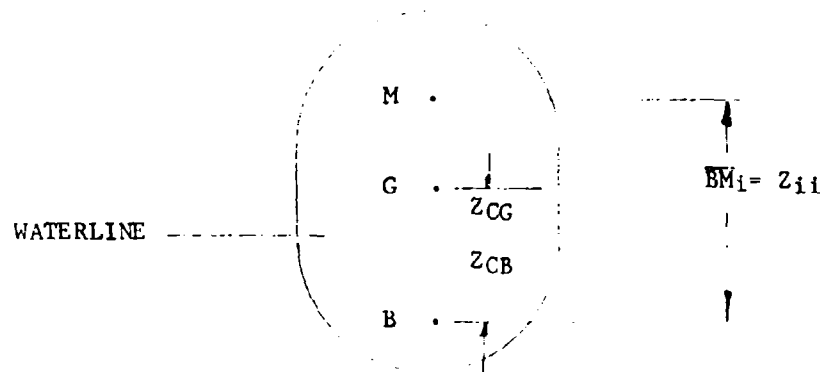
$\overline{BG}$  = distance from center of buoyancy to center of gravity G

$\overline{BG} = z_{CB} - z_{CG}$

$z_{CG}$  = distance of CG above water line  
(Negative if CG above water line)



Columbus Aircraft Division  
Rockwell International  
NR76H-137



$Z_{CB}$  = distance of center of buoyancy below waterline

$$Z_{CB} \approx H \left( \frac{1}{6} + \frac{C_b}{3C_w} \right)$$

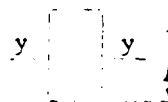
$$Z_{ii} = \frac{I_{A_{ii}}}{V} = \frac{\text{area moment of inertia}}{\text{displacement volume}}$$

$$Z_{yy} = \frac{I_{A_{yy}}}{V} = \text{distance } \overline{BM}_1 \text{ in pitch}$$

$$Z_{xx} = \frac{I_{A_{xx}}}{V} = \text{distance } \overline{BM}_1 \text{ in roll}$$

$$I_{A_{yy}} = \iint x^2 dx dy \text{ (ft}^4\text{)}$$

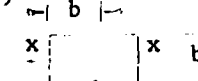
for a rectangle



$$I_{A_{yy}} = \frac{1}{12} b l^3$$

$$I_{A_{xx}} = \iint y^2(x) dy dx \text{ (ft}^4\text{)}$$

for a rectangle



$$I_{A_{xx}} = \frac{1}{12} l b^3$$

$$I_{M_{ii}} = \text{mass moment of inertia (SLUG-FT}^2\text{)} \uparrow$$

$K_{ii}$  = radius

$$I_{M_{ii}} = K_{ii}^2 m$$

$$I_{M_{yy}} = \text{mass moment of inertia in pitch}$$

$$I_{M_{xx}} = \text{mass moment of inertia in roll}$$

$$K_{ii} = \text{radius of gyration} = \sqrt{\frac{I_{M_{ii}}}{m}} = \sqrt{\frac{I_{M_{ii}}}{W/g}}$$

$$X_{CG} = \text{longitudinal CG location relative to mid ship point (positive if forward of mid ship)}$$



Columbus Aircraft Division  
Rockwell International  
NR76H-137

#### REFERENCE

1. Rockwell International Report, NR76H-113, "Sea Based Aircraft Habitability Criteria," dated 15 October 1976.
2. Massachusetts Institute of Technology Report No. 70-3, Computer Aided Prediction of Sea Keeping Performance in Ship Design, August 1970 by Theodore A. Loukakis.
3. Massachusetts Institute of Technology Report No. 69-2, "A Computerized Procedure for Prediction of Seakeeping Performance," 1969 by Dr. R. F. Beck.
4. U. S. Naval Air Engineering Center Report NAEC-ENG-7782, "Results of Analytical Response Predictions for Two Points on Helicopter Landing Platform of DLG-26 and DE-1040 (FF-1040) Class Destroyers," dated 20 November 1972.

NR76H-137

APPENDIX I

SEA STATE RELATIONSHIPS

NR76H-137  
APPENDIX I

I. SEA STATE RELATIONSHIPS

1.0 SUMMARY

Significant sea state relationships are summarized in this section for reference during the on-water motion study. More detailed information is provided in the Appendix References (particularly No. 1, 2, and 3). This section is divided into four sections, (1) Sea State Conditions, (2) Sea State Occurrence and (3) Motion Study Results.

1.1 Sea State Conditions

For reference, Table 1 (see Reference 2) and Figure 1 (see Reference 3) are included here. A representative set of sea state data has been taken from Figure 1 using median values and is shown in Table 2. The Pierson-Moskowitz sea spectra were used in the study (see Figure 2). Here

$$S\eta(\omega) = 0.0081 g^2 \omega^{-5} \exp \left[ \frac{-0.0324g^2}{(H-1/3)^2} \omega^{-4} \right]$$

where  $S\eta(\omega)$  is the wave spectra in  $\text{ft}^2\text{-sec}$  for a fully developed sea,  $g$  is acceleration in  $\text{ft/sec}^2$  and  $\omega$  is wave circular frequency in  $1/\text{seconds}$ .

Figure 3 summarizes some of the basic relationships of waves. As the sea state increases, the wave height and length both increase as shown. Because of energy considerations, the wave slope never exceeds about eight degrees. This is because the accelerations required of the water particles do not exceed the gravity force and the wave crest disintegrates (see Reference 4). Regarding on-water operation of sea based aircraft, this  $8^\circ$  wave slope indicates that roll over conditions are not excessive at zero or low water speed conditions even at high sea states.

For sea based aircraft and long duration operation stability limits may have to be based on wind wave tip over conditions. It should be remembered that open ocean conditions and long duration missions may include the 100 foot breaking wave or freak rogue waves. Obviously, if a sea plane were even tipped over it would not (like a ship) right itself.

Figure 4 is a plot of peak sea state encounter frequency at zero, 5 and 10 knots versus sea state. Thus, increasing forward velocity (by 5 or 10 knots) has a significant effect at frequencies of about 2 radians per second. A 10 knot change at this frequency is equivalent to (almost) doubling the sea state encountered. When going from sea state 2 to 4, the average wave height increases from 1.5 ft. to 3.5 ft. Since the wave energy encountered is proportional to the wave height squared;

$$E = \frac{1}{8} \rho g h^2 \quad (\text{Reference 2})$$

the relative energy change is five times.

NR76H-137  
Appendix I

Table 1. Wind and Sea Scale for Fully Arisen Sea

Sea state	Description	Wind				Sea										
		Beaufort wind force	Description	Range, knots	Wind velocity, knots†	Wave height, ft			Significant range of periods, sec	Interval of maximum energy of spectrum	T average period	L average wave-length	Minimum fetch, nmi	Minimum duration, hr		
						Average	Significant	Average highest								
0	Sea like a mirror.	0	Calm	Less than 1	0	0	0	0								
	Ripples with the appearance of scales are formed, but without foam crests.	1	Light air	1-3	2	0.05	1.08	0.10	1 <sup>†</sup> to 1.2 sec	0.7	0.5	10 in.	5	18 min		
	Small wavelets, still short but more pronounced, crests have a glassy appearance, but do not break.	2	Light breeze	4-6	5	0.18	0.29	0.37	0.4-2.8	2.0	1.1	6.7 ft	8	39 min		
1	Large wavelets, crests begin to break. Foam of glassy appearance. Perhaps scattered white horses.	3	Gentle breeze	7-10	8.5	0.6	1.0	1.2	0.8-5.0	3.4	2.1	20	9.8	17.1 <sup>†</sup>		
					10	0.88	1.4	1.5	1.0-6.0	4	2.9	27	10	2.4		
					12	1.4	2.2	2.8	1.0-7.0	4.8	3.4	40	18	3.8		
2	Small waves, becoming larger; fairly frequent white horses.	4	Moderate breeze	11-16	13.5	1.8	2.9	3.7	1.4-7.6	5.4	3.9	53	21	4.8		
					14	2.0	3.3	4.2	1.5-7.8	5.6	4.0	59	28	5.2		
					16	2.9	4.6	5.8	2.0-8.8	6.7	4.6	71	40	6.6		
3	Moderate waves, taking a more pronounced long form; many white horses are formed (chance of some spray).	5	Fresh breeze	17-21	18	3.8	6.1	7.8	2.5-10.0	7.2	5.1	90	55	8.3		
					19	4.3	6.9	8.7	2.8-10.0	7.7	5.4	99	65	9.2		
					20	5.0	8.0	10	3.0-11.1	8.1	5.7	111	75	10		
4	Large waves begin to form; the white foam crests are more extensive everywhere (probably some spray).	6	Strong breeze	22-27	22	6.4	10	13	3.4-12.2	8.9	6.3	131	100	12		
					24	7.9	12	16	3.7-13.5	9.7	6.8	160	150	14		
					21.5	8.2	13	17	3.8-13.6	9.9	7.0	161	140	15		
5	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind (spindrift begins to be seen).	7	Moderate gale	28-33	26	9.4	15	20	4.0-14.5	10.5	7.1	188	180	17		
					28	11	18	23	4.5-15.5	11.3	7.9	212	230	20		
					30	14	22	28	4.7-16.7	12.1	8.6	250	280	23		
6	Moderately high waves of greater length; edges of crests break into spindrift. The foam is blown in well-marked streaks along the direction of the wind. Spray affects visibility.	8	Fresh gale	34-40	30.8	14	23	29	4.8-17.0	12.4	8.7	258	290	24		
					32	16	26	33	5.0-17.5	12.9	9.1	285	310	27		
					34	19	30	38	5.5-18.5	13.6	9.7	322	420	30		
7	High waves. Dense streaks of foam along the direction of the wind. Sea begins to roll. Visibility affected.	9	Strong gale	41-47	37	23	37	46.7	6.20-5	11.9	10.5	376	530	37		
					38	25	40	50	6.2-20.8	15.4	10.7	392	580	38		
					40	28	45	58	6.5-21.7	16.1	11.4	444	710	42		
8	Very high waves with long overhanging crests. The resulting foam is in great patches and is blown in dense white streaks along the direction of the wind. On the whole, the surface of the sea takes a white appearance. The rolling of the sea becomes heavy and shock-like. Visibility is affected.	10	Whole gale*	48-55	42	31	50	64	7-23	17.0	12.0	492	820	47		
					44	36	58	73	7-21.2	17.7	12.5	531	960	52		
					46	40	64	81	7-25	18.8	13.1	599	1110	57		
9	Exceptionally high waves (small and medium-sized ships might for a long time be lost to view behind the waves). The sea is completely covered with long white patches of foam lying along the direction of the wind. Everywhere the edges of the wave crests are blown into foam. Visibility affected.	11	Storm*	56-63	48	44	71	90	7.5-26	19.4	13.8	650	1250	63		
					50	49	78	99	7.5-27	20.2	14.3	760	1420	69		
					51.5	52	83	106	8.28-2	20.8	14.7	736	1560	73		
10	Air filled with foam and spray. Sea completely white with driving spray; visibility very seriously affected.	12	Hurricane*	64-71	52	54	87	110	8.28-5	21.0	14.8	750	1610	75		
					54	59	95	121	8.29-5	21.8	15.4	810	1800	81		
					59.5	73	116	148	10-32	24	17.0	985	2500	101		

\* For hurricane winds (and often whole gale and storm winds) required durations and fetches are rarely attained. Seas are therefore not fully arisen.

† A heavy box around this value means that the values tabulated are at the center of the Beaufort range.

‡ For such high winds, the seas are confused. The wave crests blow off, and the water and the air mix.

Source: W. A. McEwen and A. H. Lewis, "Encyclopedia of Nautical Knowledge," p. 483, Cornell Maritime Press, Cambridge, Md., 1953. "Manual of Seamanship," pp. 717-718, vol. II, Admiralty, London, H.M. Stationery Office, 1952. Pierson, Neumann, James, "Practical Methods for Observing and Forecasting Ocean Waves," New York University College of Engineering, 1953.

st Available Copy

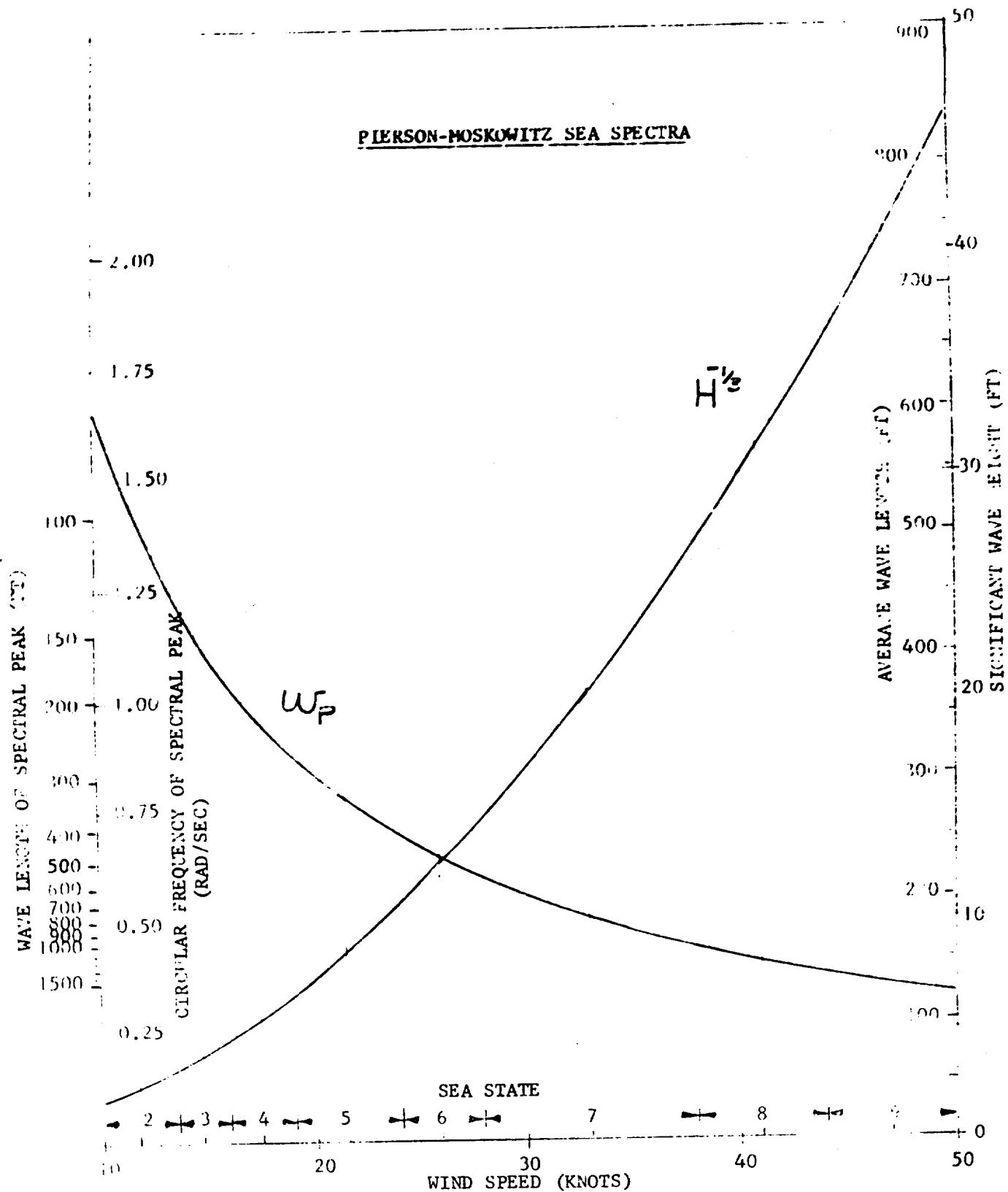


FIGURE 1. PRINCIPAL PARAMETERS FOR FULLY DEVELOPED SEAWAYS



NR76H-137  
Appendix I

Table 2. Pierson-Moskowitz Median Sea Spectra Values

Sea State	Significant Wave Height $H^{1/3}$ (ft.)	Average Wave Length $\lambda_{AV}$ (ft.)	Average Wave Height $\bar{H}_{AV}$ (ft.)	Circular Freq. of Spectral Peak $\omega_P$ (RAD/SEC)	Wave Length of Spectral Peak $\lambda_P$ (ft.)	Average Wind Speed (Knots)
1	1.0	18	.63	3.14	39	5
2	2.4	42	1.5	1.45	95	11.7
3	4.0	72	2.5	1.15	152	14.7
4	5.6	102	3.5	.951	225	17.3
5	8.6	156	5.4	.755	336	21.5
6	12.6	229	7.9	.64	490	26.0
7	20.3	368	12.7	.51	790	33.0
8	31.2	567	19.5	.40	1270	41.0
9	41.0	746	25.7	.35	1570	47.0

$$\lambda_P = 39.016 H^{-1/3}$$

$$\frac{\bar{H}}{H} = 1.272 H^{-1/3}$$

$$\bar{H}/\lambda_{AV}^{1/2}; \text{ for } H^{-1/3}, \bar{\theta} = 6.3^\circ$$

$$\bar{H}_{AV} = .626 H^{-1/3}$$

$$\lambda_{AV} = 18.16 H^{-1/3}$$

$$\bar{\theta} \text{ Ave Wave Slope } \approx \text{Arc Tan for } \bar{H}^{1/40}, \bar{\theta} = 8^\circ$$

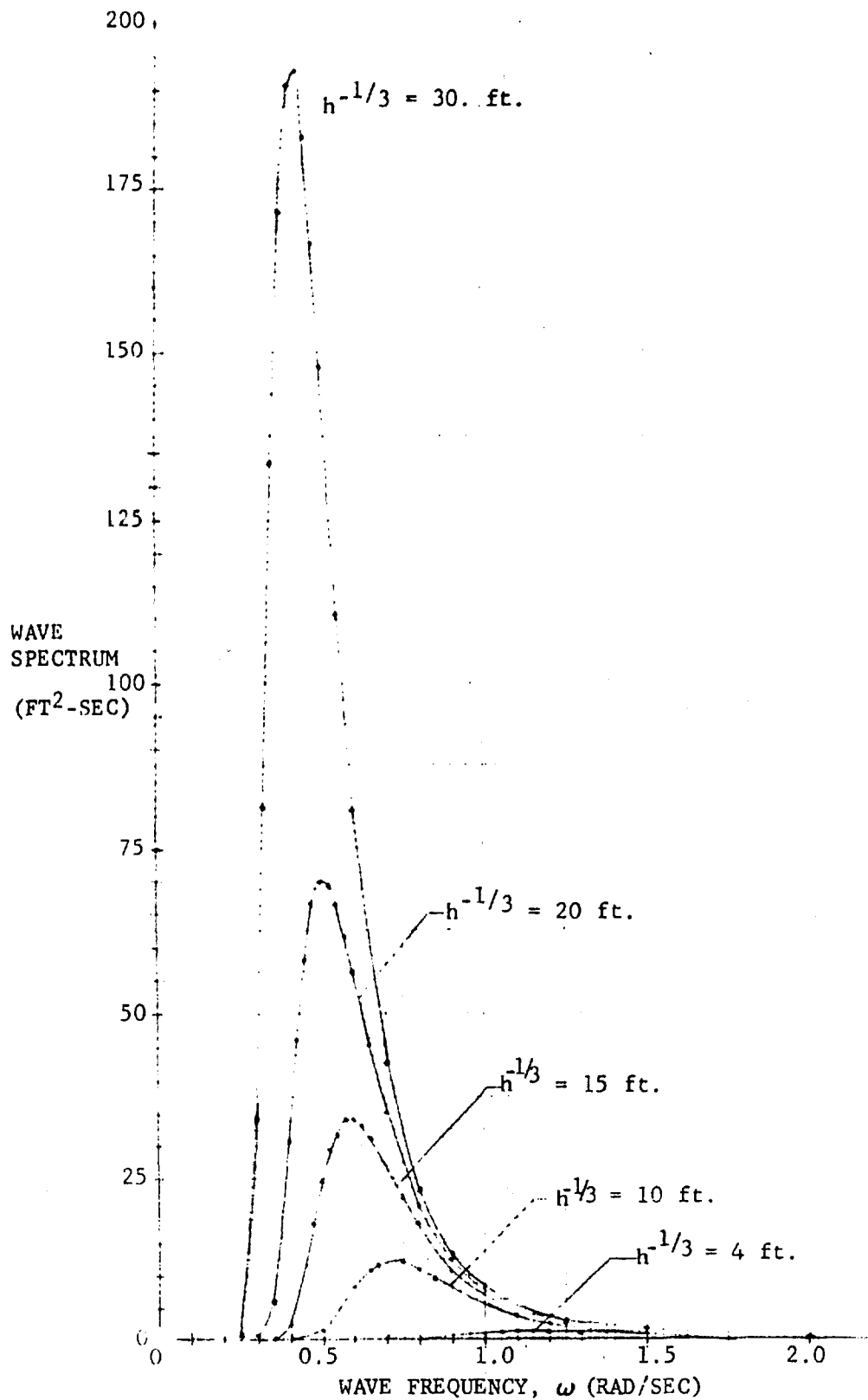


FIGURE 2. WAVE SPECTRUM VS WAVE FREQUENCY

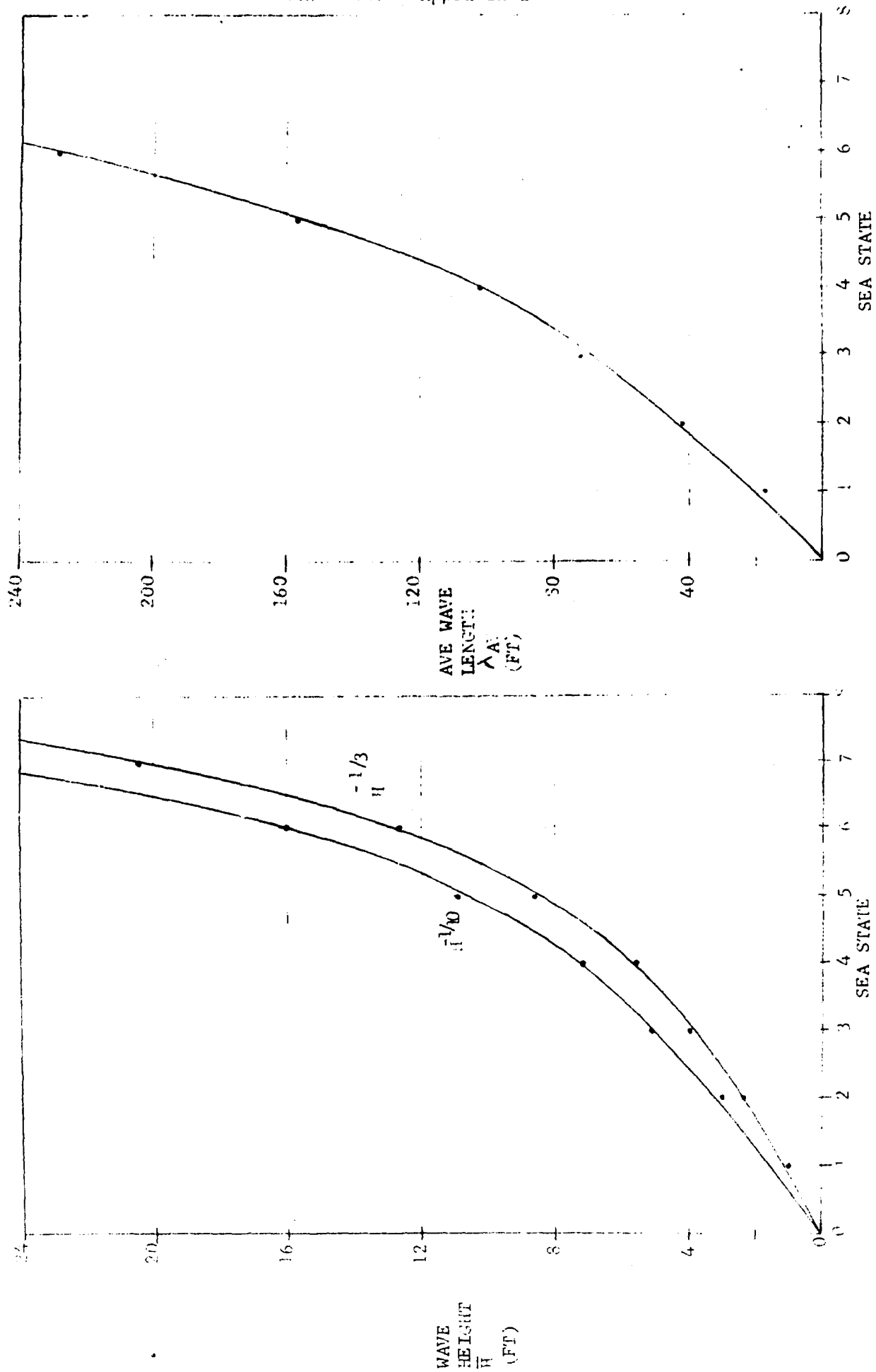


FIGURE 3. WAVE HEIGHT AND AVERAGE WAVE LENGTH VS. SEA STATE (PIERSON-MOSKOWITZ MEDIAN VALUES)

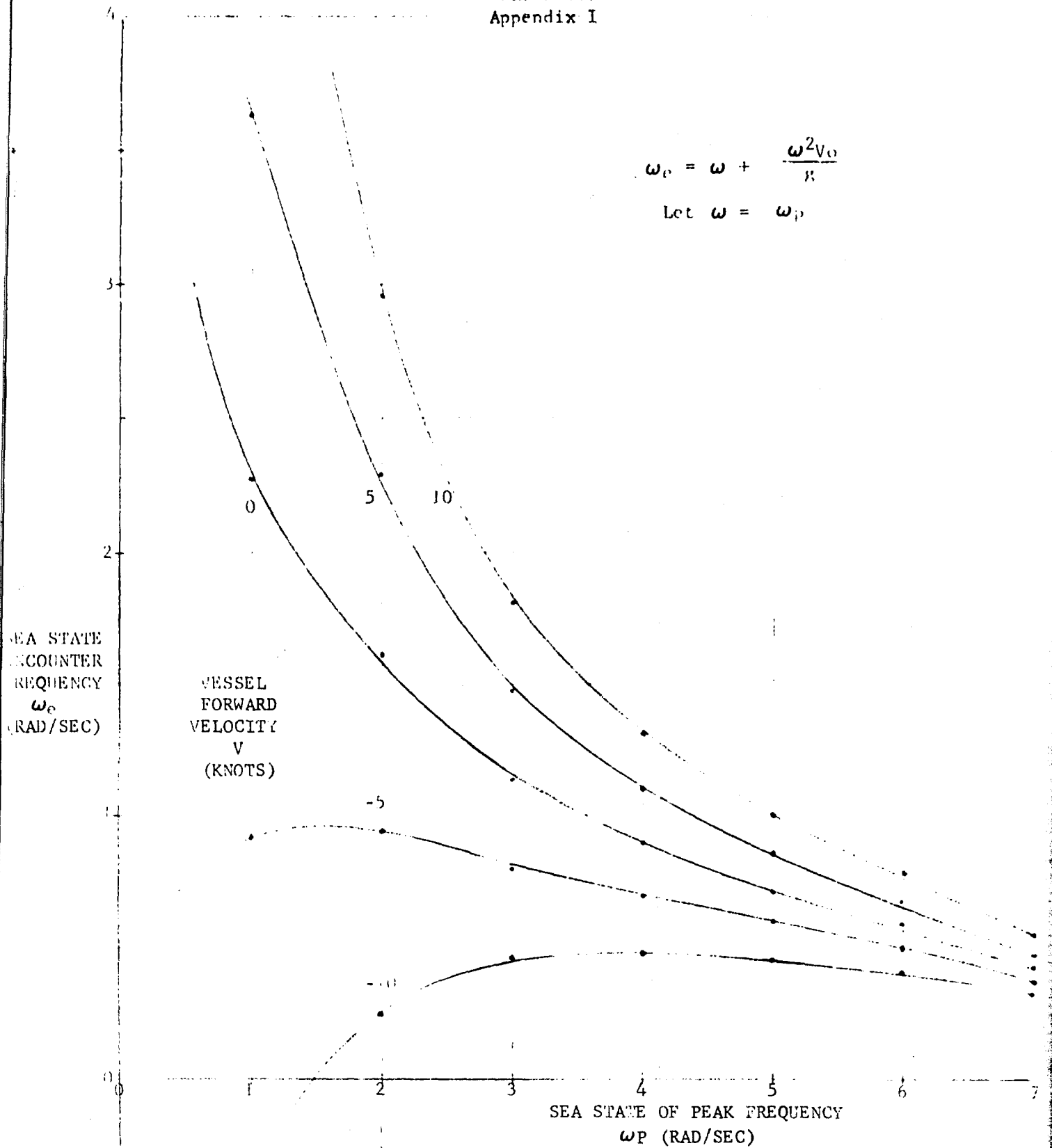


FIGURE 4. SEA STATE ENCOUNTER FREQUENCY VS SEA STATE

## 1.2 Sea State Occurrence

The occurrence of various sea conditions has been studied in Reference 14, 15, and 16. Figures 5 and 6 are from data taken from Reference 14 and 16 respectively. The operational capability of the PBY and P5M (Figure 6) are shown as circles. For example, the PBY was designed for operation in seas with three foot waves (or about Sea State 2). This constituted about 15 to 18 percent of the time in the Atlantic and Pacific Oceans. The P5M was designed for operation in four foot waves (about Sea State 2 1/2) or about 24 percent of the time. Much greater use of these craft was actually made (see Reference 15) with resultant high loss rates. It should be remembered that the values of Figure 5 are based on average occurrences as observed over the total ocean area and do not reflect the expected occurrence for shipping lanes (which avoid high sea state ocean areas), required ASW areas, etc.

Figure 5 is from Reference 16 that indicates the extreme values of waves (for design of structures to last vs. lifetime). Based on material at hand (Reference 2), the asymptotic wave height for the North Atlantic is 90 feet. The resultant modified Galton distribution (Reference 16) is in Figure 5.

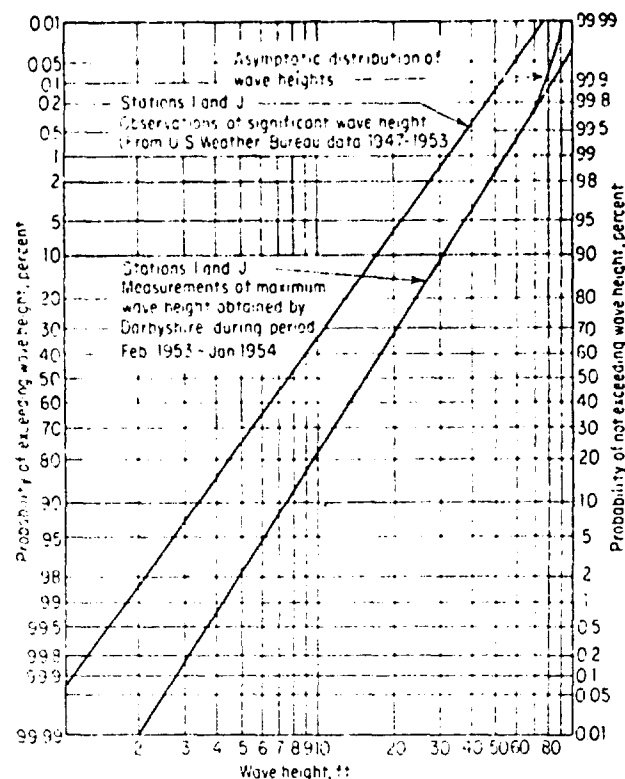


FIGURE 5. WAVE-HEIGHT DATA FOR THE NORTH ATLANTIC

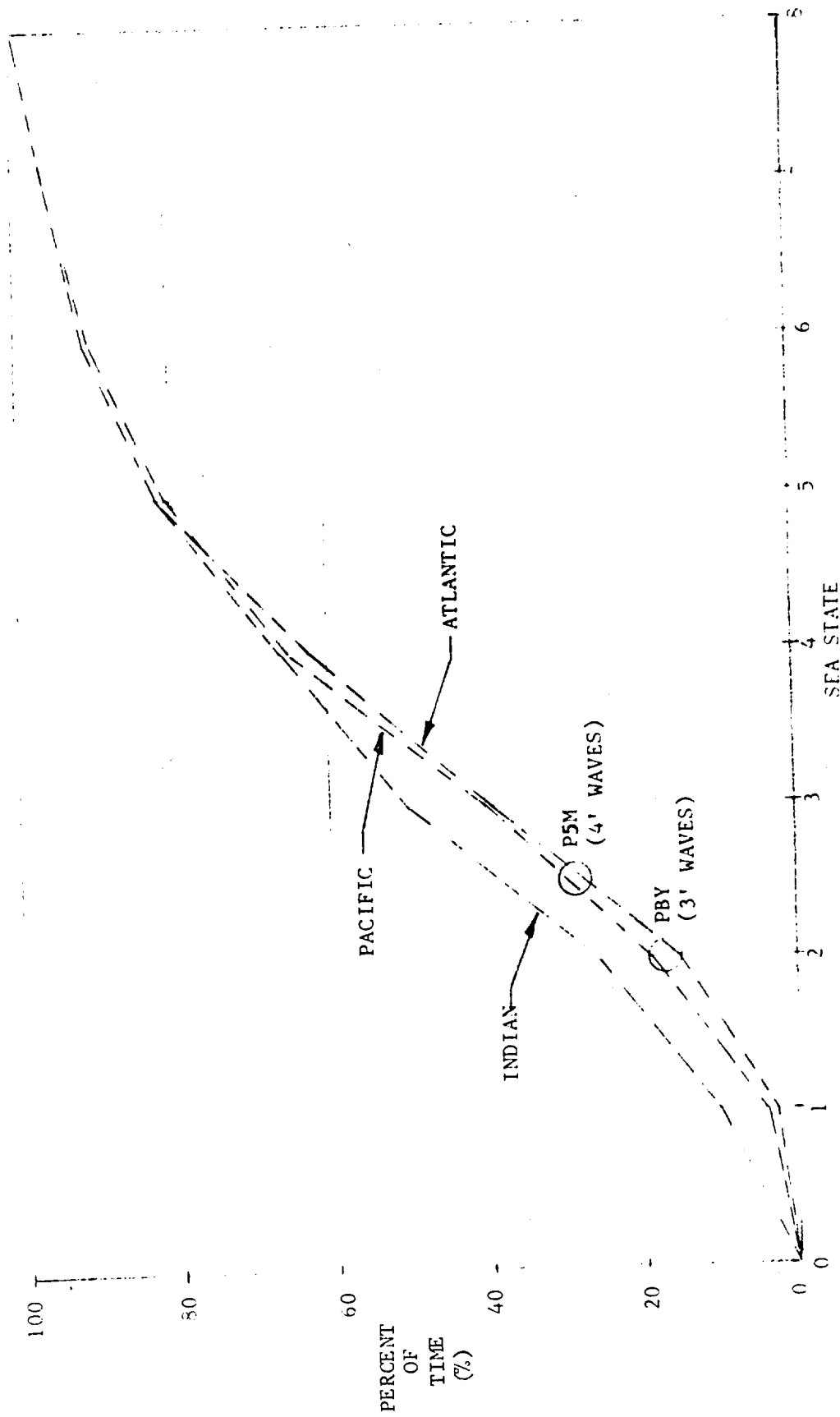


FIGURE 6. FREQUENCY OF DIFFERENT SEA STATES

NR76H-137  
Appendix I

The estimated operating capability of various aircraft and ships is shown in Table 3.

Table 3. Estimated Operating Capability

SYSTEM	MAXIMUM OPERATING WAVE HEIGHT	AVERAGE SEA STATE FOR INDICATED WAVE HEIGHT	ESTIMATED PERCENT OF TIME SYSTEM CAN OPERATE
PBY	3	2½ - 3	30 - 50% *
P5M	4 - 5	3	40 - 50% *
PS-1	10	4½	72 - 74% *
V/STOL SEA BASED AIRCRAFT	15 - 20	6 - 6½	90 - 93%
CV	20	6½	93% *
AIRFIELD	--	--	98%

\* Sea State limited time only

Reference 15 indicates that PBY and P5M craft, when water based, were also limited by weather conditions existing at the forward area sea dome where wind and sea were often worse than provided for in basic flying boat design criteria. Amphibious craft have a higher availability being able to make use of land or water bases. V/STOL aircraft that can operate from ships as well as being amphibious would have the highest possible availability of the craft indicated in Table 3.

As a result, the estimated percent of time indicated for the PBY and P5M are high in that base weather limitations have not been included. The percent of time values for PS-1 and V/STOL sea based aircraft are correspondingly low as their basing flexibility would improve the percent of time they could operate. While the actual operability times are mission dependent, a V/STOL sea based aircraft with both land, ship and high sea state capability should have operability comparable to CV craft and land based airfields.

### 1.3 On-Water Motion Study

Fundamental relationships regarding vessel motion on the water are summarized in this section. This work is the result of a V/STOL aircraft on-water motion analysis performed by Rockwell International, Columbus Aircraft Division.

NR76H-157  
Appendix I

1.3.1 Study Summary

On-water motions of stationary catamaran and single hull aircraft were analyzed and compared to other ocean vessels. Forward velocity on the water was not considered in this analysis. Equations of motion and acceleration were developed for heave, roll, pitch, and acceleration. The analysis performed involved uncoupled equations of heave, roll, and pitch. The developed data provided a good insight into the relative motion of the vehicles analyzed. It did not provide absolute values of motion or acceleration. Coupled equations of motion are necessary to provide this information.

As a result of this analysis, however, several significant conclusions regarding sea based aircraft have been determined. These are:

1. Small size amphibian aircraft (under 50 feet in length and under 50,000 pounds) that have low draft so that they "ride with the waves" have acceptable motion and acceleration characteristics for high sea state on-water operation. Aircraft lengths that are a fraction of a wave length at high sea states (so that the aircraft follows the waves) do not have to take severe bending loads, see Figure 7. Important characteristics are hull length and wing span between floats or distance between hulls on a catamaran. Hull lengths and spans of 35 to 50 feet are considered best. This is based on motion and wing/fuselage bending load considerations; the latter being proportional to fuselage length and wing span. These general length and span characteristics are those of Kon Tiki type (surface following) craft which have good open ocean motion and acceleration characteristics.

For riding on the water at high sea states, important aircraft design limits are length and span. These should be small (preferably about 50 feet) and never more than 100 feet. Load alleviation devices or articulation may be required at these lengths. This is based on Figure 8, which indicates that above an average wave length ( $\lambda$ ) of 100 feet, wave heights and consequently roll and pitch motion and bending moments, increase sharply. At  $\lambda = 100$  feet, the one-tenth highest wave height ( $H_1/10$ ) is about 13 feet while at  $\lambda = 200$  feet,  $H_1/10 = 16$  feet.

Crew comfort is a question of becoming seasick due to adverse motions and accelerations. All of the vehicles considered have relatively low accelerations considering the motions and accelerations of a ship making headway in rough seas. A 500 foot ship at 25 knots in sea state 6 to 7 will have bow accelerations over 1 g. While accelerations in a stationary small craft may be such as to cause seasickness for an operator on his first cruise, the motions are much less severe than those that could be expected by



I MOTION/ACCELERATION

FORCING FUNCTION  $\propto$  TO  
WATER PLANE AREA (S)

WATER FORCE = PRESSURE  $\times$  AREA (S)  $\times$  WAVE HEIGHT  
 $64,000 \text{ LBS} = 64 \text{ LBS/FT}^3 \times 1000 \text{ FT}^2 \times 1 \text{ FT.}$

II PITCHING/BENDING MOMENT

$\propto \frac{\text{HULL LENGTH}}{\text{WAVE LENGTH}} \times \text{WAVE HEIGHT}$   
( $\lambda$ )

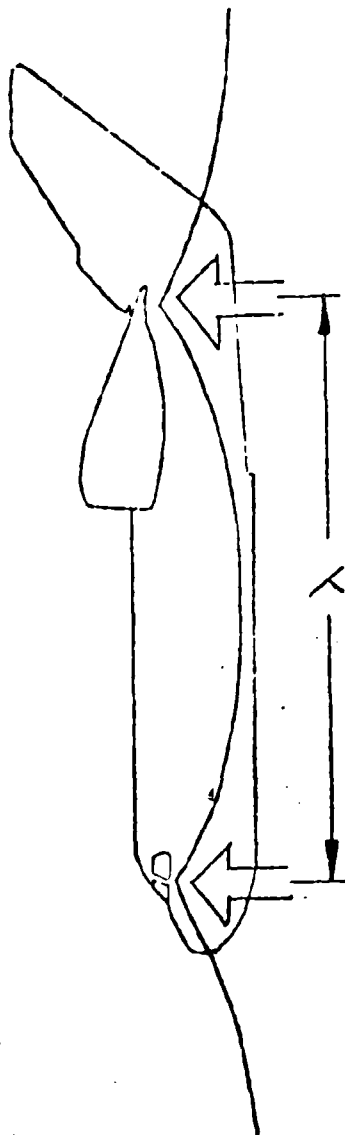


FIGURE 7. SIGNIFICANCE OF AIRCRAFT LENGTH

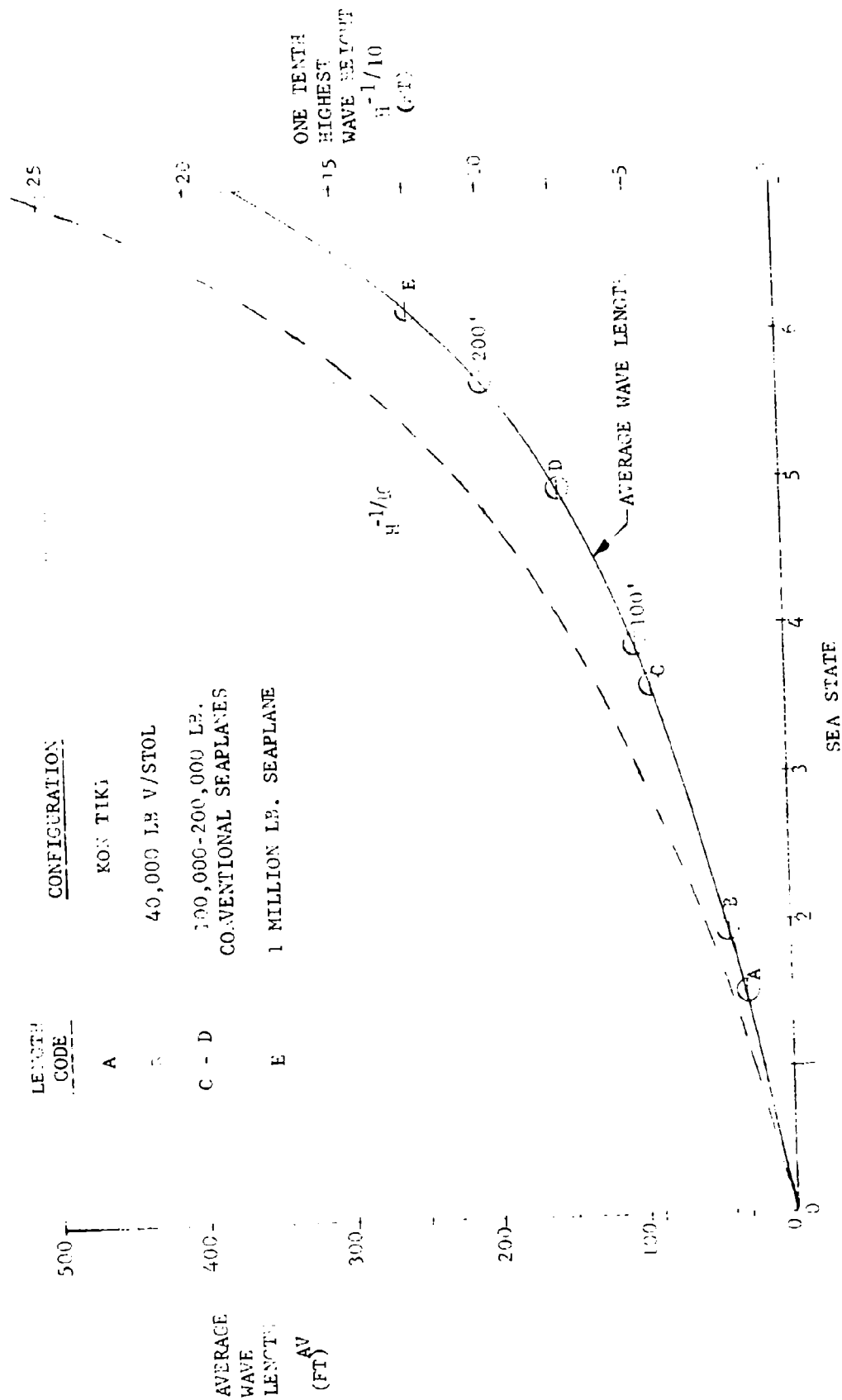


FIGURE 8. SIGNIFICANCE OF AIRCRAFT LENGTH

NR76H-137  
Appendix I

a crewman aboard a destroyer or cruise at cruise speeds. Except for initial mission seasickness, the motions for either a 50 foot length or 100 foot length sea based aircraft should not adversely affect crew performance.

2. Sea based aircraft in the TOGW range of 100,000 pounds to 250,000 pounds should also have acceptable motion characteristics, provided that on the water speeds required are not significant (over 5 to 10 knots). Design conditions that are a function of aircraft size, bending loads, etc., will establish the practicability of these larger aircraft.
3. One overriding point that came out of this analysis is the significance of on water velocity on vessel motion and acceleration. Ships have motion and acceleration problems because they are trying to make headway even in rough seas. Past seaplanes which had to land and takeoff at speeds of 75 to 100 knots over high waves or swells also encountered significant acceleration and loading problems.
4. Beam sea conditions that result in high transverse loads and accelerations should be avoided because of the lower human tolerance to transverse accelerations (about half that of vertical acceleration tolerances). This requires an on-water propulsion device for on-water mobility so that the craft does not have to use in flight engines.
5. Sea based aircraft could be designed to have a deep draft to have little motion on the water. An example of this would be a P5M with verta floats. When this is done however, 1) strength must be added to take the increased bending loads encountered on the floats or hull and 2) height above the water must be provided to clear the maximum wave height expected operationally. Fuselage and wing bending loads are proportional to fuselage/float span length and draft. A sea state of 6 has a wave length of over 200 feet and wave heights (peak-to-trough) of up to 13 to 16 feet. Under this condition, a 800,000 pound plane with a 200 foot length fuselage that is 20 feet in depth would be primarily submerged at the nose and tail (and thus largely supported at the nose and tail). The fuselage bending moment would be about 80 times those for a 50 foot length sea based aircraft (see Figure 9).

The 4.5g flight loads for a 40K, 50 ft. aircraft are about equivalent to the expected on water bending loads.

NR76H-137  
Appendix I

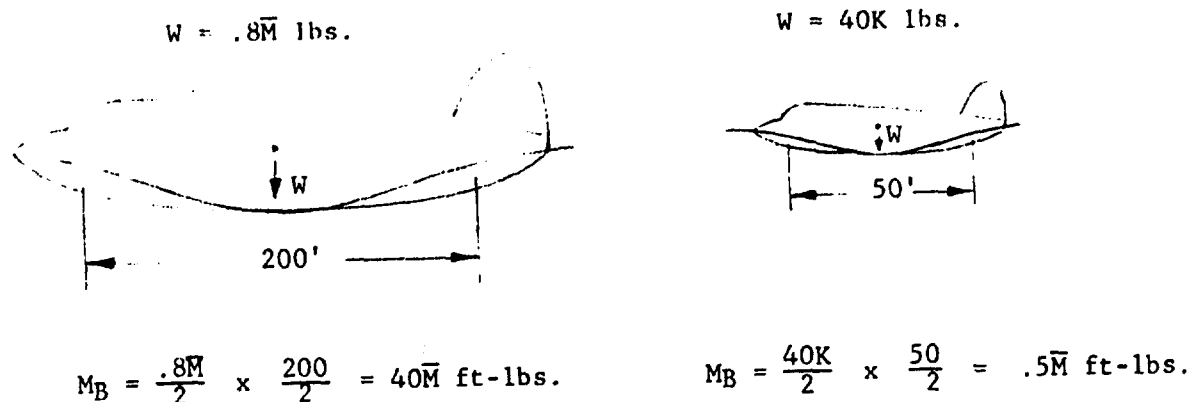


FIGURE 9. COMPARISON OF FUSELAGE BENDING LOADS,  $M_B$

For large seaplanes to operate in high sea states, bending loads must be alleviated to avoid excessive loading conditions.

A 50 foot seaplane would not have to span these high waves and would always be on one slope of the wave. The waves it would span would be at sea state 2.4, where the 1/10 highest waves are less than 4 feet high.

A 200 foot seaplane would have to span sea state 5 to 6 waves with the 1/10 highest waves of 12 to 17 feet. The bending loads are much higher here compared to flight bending requirements.

### 1.3.2 Stability Considerations

Figure 10 compares the static lateral stability of two sea based concepts with seaplanes of the past. Because of the need to keep the wings and engines out of the water, seaplanes had high wing locations with engines mounted on top that resulted in high c.g.'s and large disturbing moments (DM). Compared to the catamaran design presented, the disturbing moments were 2 to 3 times larger. This would also be true of any new large seaplane that was designed to keep the engines out of any conventional water takeoff spray condition.

All three designs meet the stability requirements shown in Figure 11 ( $14 \times 10^4 \text{ lb-ft}$ ) at  $\theta = 10^\circ$ .

45,000 LB. TOGW

	REPRESENT- ATIVE V/STOL CATANARAN	REPRESENT- ATIVE SEAPLANE	REPRESENT- ATIVE V/STOL SINGLE HULL
$h$ (Ft)	2.7-3.0	7.5-9.0	2.2
DM (Ft. Lbs.) $\theta = 5^\circ$	9400	25,000	9154
$L$ (Ft)	6	35-40	26
$\Delta$ (Lb) $\theta = 5^\circ$	12,150	2150	3000
RM (Ft. Lbs.) $\theta = 5^\circ$ $\theta = 10^\circ$	73,000 150,000	80,000 150,000	78,400 150,000
$\frac{RM}{DM}$ ( $\theta = 5^\circ$ )	7.75	3.2	8.6

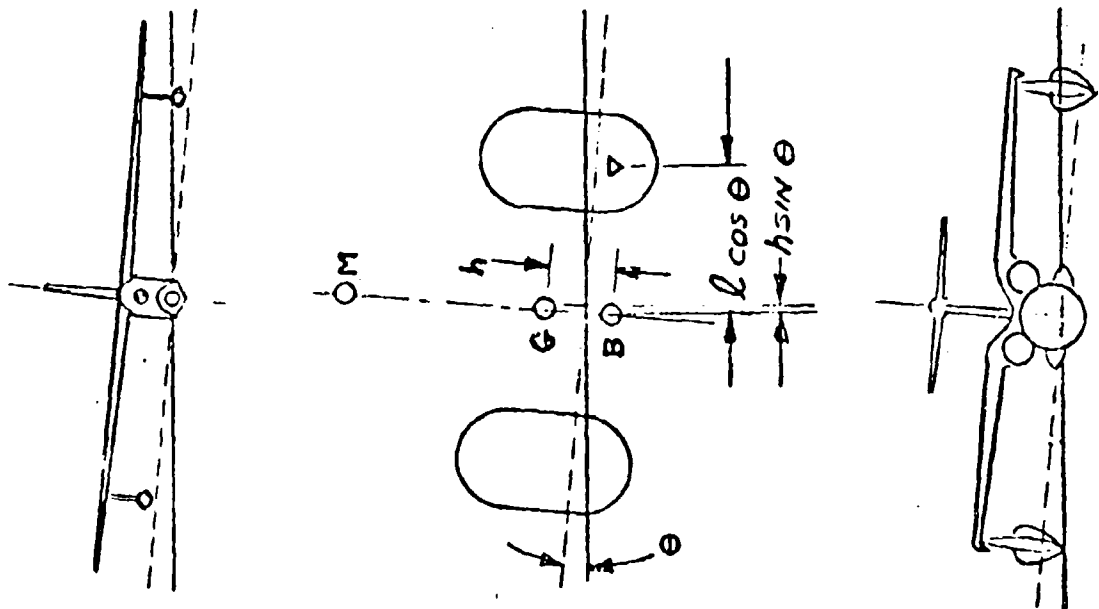


FIGURE 10. Stability Comparison

NR76H-137  
Appendix I

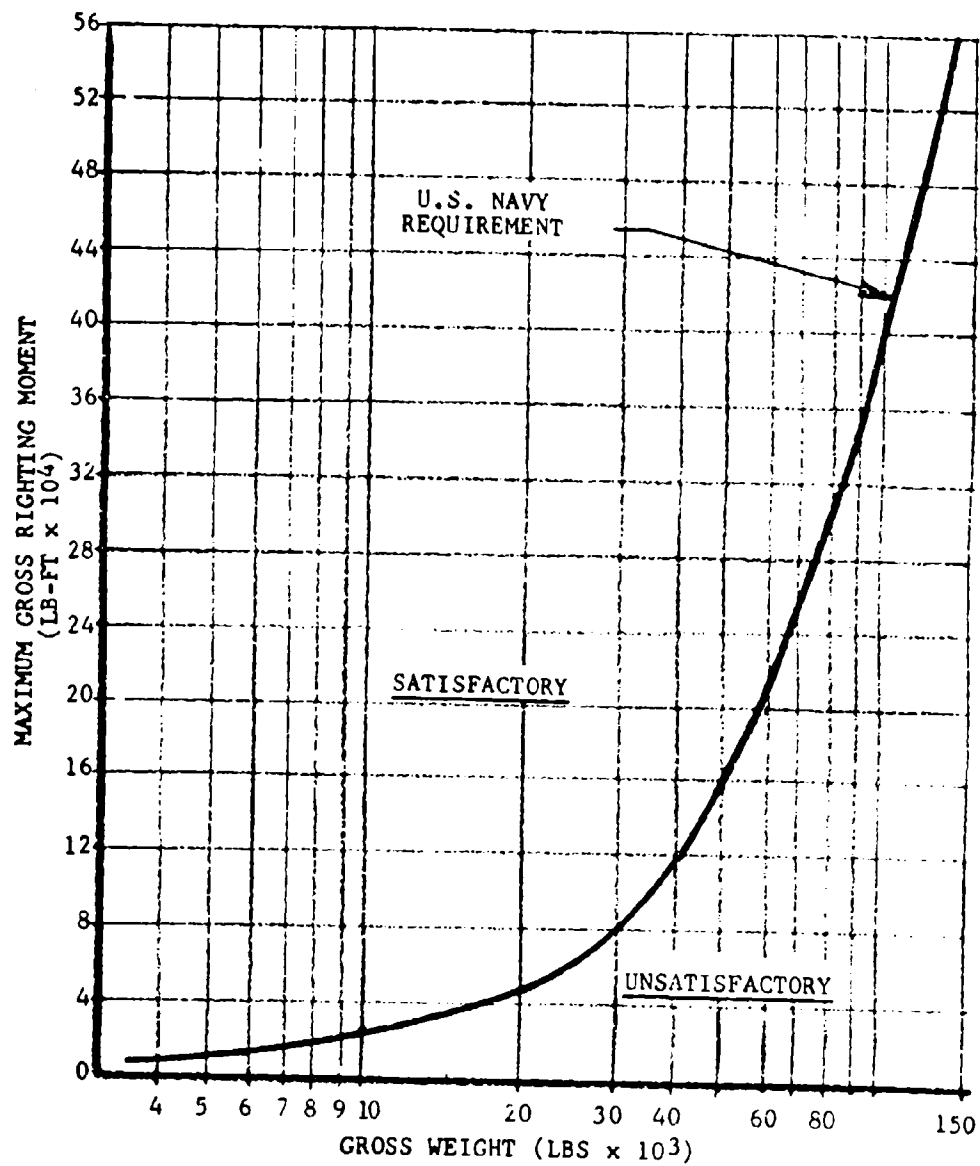


Figure 11 On-Water Stability Requirement

NR76H-137  
Appendix 1

The restoring moments of a single hull seaplane are determined by the outboard float volume and the moment arm length. Once the float is under the water, a maximum restoring moment has been reached. Conventional takeoff seaplanes have in the past, been designed so that there is some float clearance on landing, and thus, when sitting on the water, the seaplane rocks back and forth resting on one float and then the other.

A catamaran always has an increasing righting moment with any magnitude of disturbance, and at a roll angle of five degrees has twice the static stability of past typical seaplanes. In addition, since bending loads are proportional to length, the outboard float seaplane will be subject to significantly higher bending moments than would a catamaran.

NR76H-137  
Appendix I

REFERENCES

I Sea State Relationships

1. H. O. Publication No. 604, "Practical Methods of Observing and Forecasting Ocean Waves by Means of Wave Spectra and Statistics," U. S. Navy Hydrographic Office, dated 1955.
2. Handbook of Ocean and Underwater Engineering, Myers, Holm and McAllister, Rockwell Corporation, dated 1969.
3. Massachusetts Institute of Technology Report No. 70-3, Computer Aided Prediction of Sea Keeping Performance in Ship Design, August 1970 by Theodore A. Loukakis.
4. Appendix 2 of Heavy Weather Sailing by K. Adland Coles, Tuckahoe, New York, 1968.
5. Possibilities for Reducing Ship Motions at Sea by Edward V. Lewis, Journal of American Society of Naval Engineers, Nov. 1958.
6. "On the Motion of Floating Bodies" Part II Simple Harmonic Motions, Communications on Committee of Pure Applied Mathematics Volume 3, by Fritz John 1950 (QAL. C734).
7. "Ship Motions Prediction Realistic Short-Crested Seas" by Z. G. Wachnick, and E. E. Zarnick, Society of Naval Architects and Marine Engineers, Nov. 11-12, 1965.
8. Symposium on Ship Operation, Part 1, How They Perform by R. O. Patterson.
9. LPD Motion Study, NSRDC, M. Sekellick, 27 July 1971.
10. Mechanical Vibrations, Den Hartog, McGraw-Hill, 1956.
11. Study of Hydrofoil Seacraft, Grumman Report PB 151475 for the Department of Commerce.
12. Supercritical Planning Hulls by Peter R. Payne, AIAA Paper (CL 26822) No. 74-333 February 1974 (H029279).
13. The Potential of Semi-Submerged Ships in Rough Water Operation, by Philip Mandel, MIT, SNAME, March 1960 (CL 26821).



REFERENCES (Continued)

II Sea State Occurrence

14. Calspan Report No. GM-1968-1 "Open Ocean ASW Air-Sea Craft System Feasibility Study (U)," Volume III Air Sea Craft Operational Sea Environment (AD507576L), dated 1968.
15. U. S. Navy Report Operational History of the Flying Boat Open Sea and Seadrome Aspects - Selected Campaigns of World War II (CL 28405), dated Jan. 1959.
16. Soc. of Naval Arch. Marine Engrs. Tech. Res. Bull. 1-19, Height, Length and Steepness of Seawaves in the North Atlantic and Dimensions of Seawaves as Functions of Wind Forces (trans. by M. St. Denis). Roll, H. V., 1958.

NR76H-137

APPENDIX II

RESPONSE AMPLITUDE OPERATORS (RAO'S)

NR76H-137  
Appendix II

RESPONSE AMPLITUDE OPERATORS (RAO'S)

Based on the theory of linear systems, the spectral density of the response,  $S(\omega)$  can be found from the relation

$$S_{\text{response}}(\omega) = |H_j(\omega)|^2 S_{\text{wave}}(\omega)$$

where:

$H_j(\omega)$  = frequency response operator of the craft (RAO) for craft response  $j$

$S_{\text{wave}}(\omega)$  = the spectral density of the seaway (wave spectrum)

$S_{\text{response}}(\omega)$  is the mean squared amplitude of the response

Thus, the RAO is the transfer function of the craft and indicates how the craft responds in heave, pitch, etc., per unit of wave spectrum input.

The RAO's are for regular waves and the response is in a seaway (or applies to irregular waves).

Figures 1 through 14 are for configurations 1 through 6. Figure 15 is the wave spectrum plotted to be overlaid on the RAO's. As indicated in Figure 15, the wave energy is found in the frequency range from 0.4 radians/second to 1.5 radians/second at zero speed with the peak frequency decreasing as sea state increases. Thus, most of the high sea state energy is in the frequency band of .75 to .4 radians/second.

Examining the RAO's of Figure 1 through 14 indicates that only configuration 1 has any significant heave, pitch or cockpit vertical acceleration RAO's in this critical frequency band. Also, from Figure 2 and 3, notice the heave and pitch coupling that exists (the bump in the heave RAO at 0.6-0.7 radians/second at the peak pitch amplitude). This explains the high pitch amplitudes and accelerations of Configuration 1, particularly at the higher significant wave heights (or sea states). The high values of pitch and cockpit acceleration RAO's for configurations 3 through 6 are not particularly significant as they occur near or above 2 radians/second. As speed increases, however, these RAO's peaks become more significant.

Figure 16 indicates how the peak frequency changes as on water speed is changed from zero to  $\pm 10$  knots. The major effect for an RAO at 2 radians/second is at the sea states of 2 to 4 ( $H^{1/3} = 2.4$  to 5.6 feet) when the frequencies of encounter are increased from 1.6 and 0.9 radians/second to 2.95 and 1.3 radians/second. The acceleration RAO peaks for configurations 3, 4, 5 and 6 would explain the generally higher levels of RMS acceleration at zero and 5 knots compared to configuration 2.

NR76H-137  
Appendix II

Selective hull shaping or slight increases in hull length should be examined to see if configurations 3, 5 and 6 could be improved. Configuration 4 is longer (43 feet) and has a somewhat lower RMS acceleration level. From Figure 15, lengthening to 40 to 45 feet and hull shaping would seem to provide RMS g levels of 0.1 at 0 knots and 0.2 to 0.25 at 5 knots at a significant wave height of 15 feet (sea state 6). Optimizing hull length and selective shaping should provide a 10 to 15 percent improvement in RMS g level reduction.

NR76H-137  
Appendix II

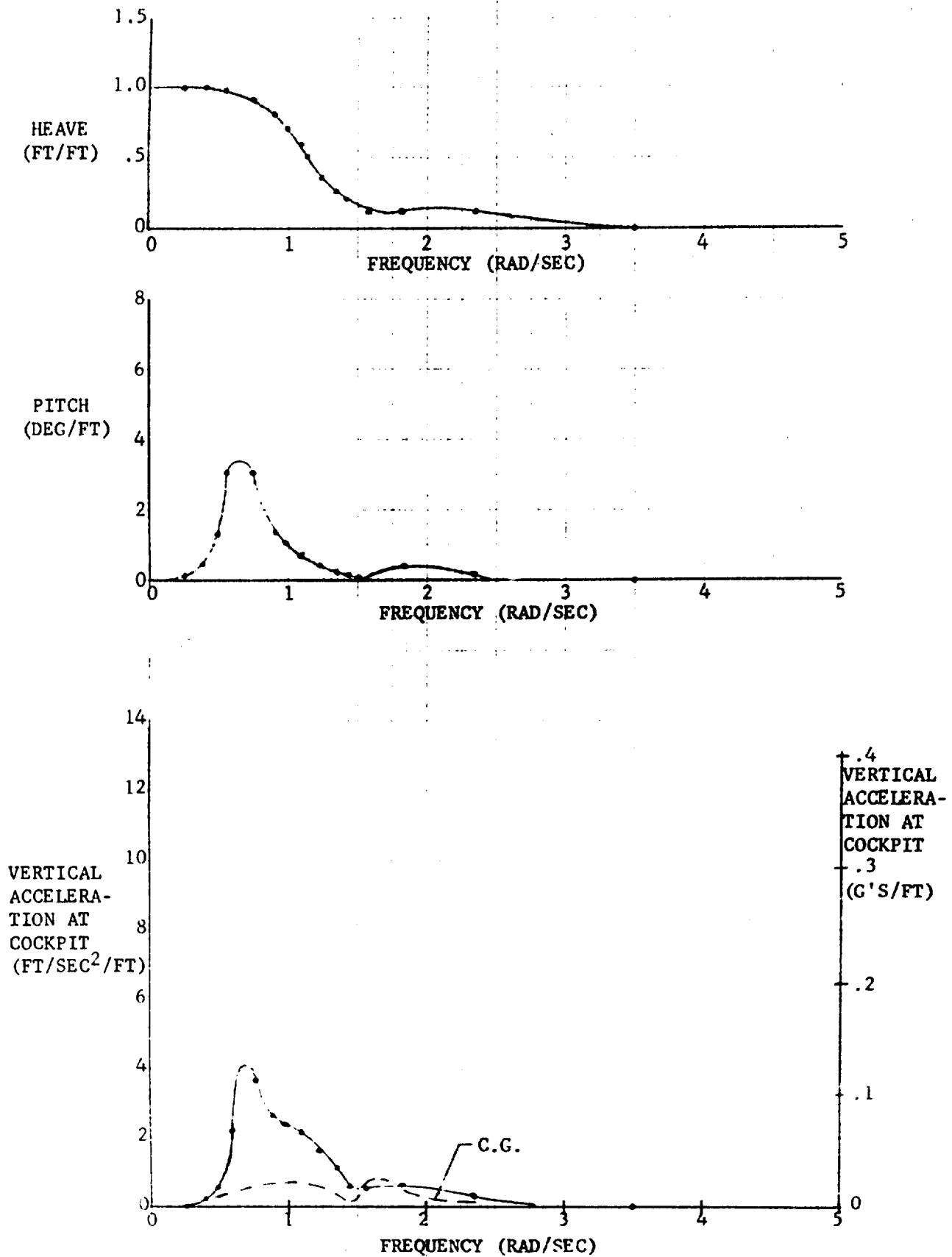


FIGURE 1. RESPONSE AMPLITUDE OPERATORS V = 0 KNOTS  
CONFIGURATION 1 CTOL CAT 1.25M

NR76H-137  
Appendix II

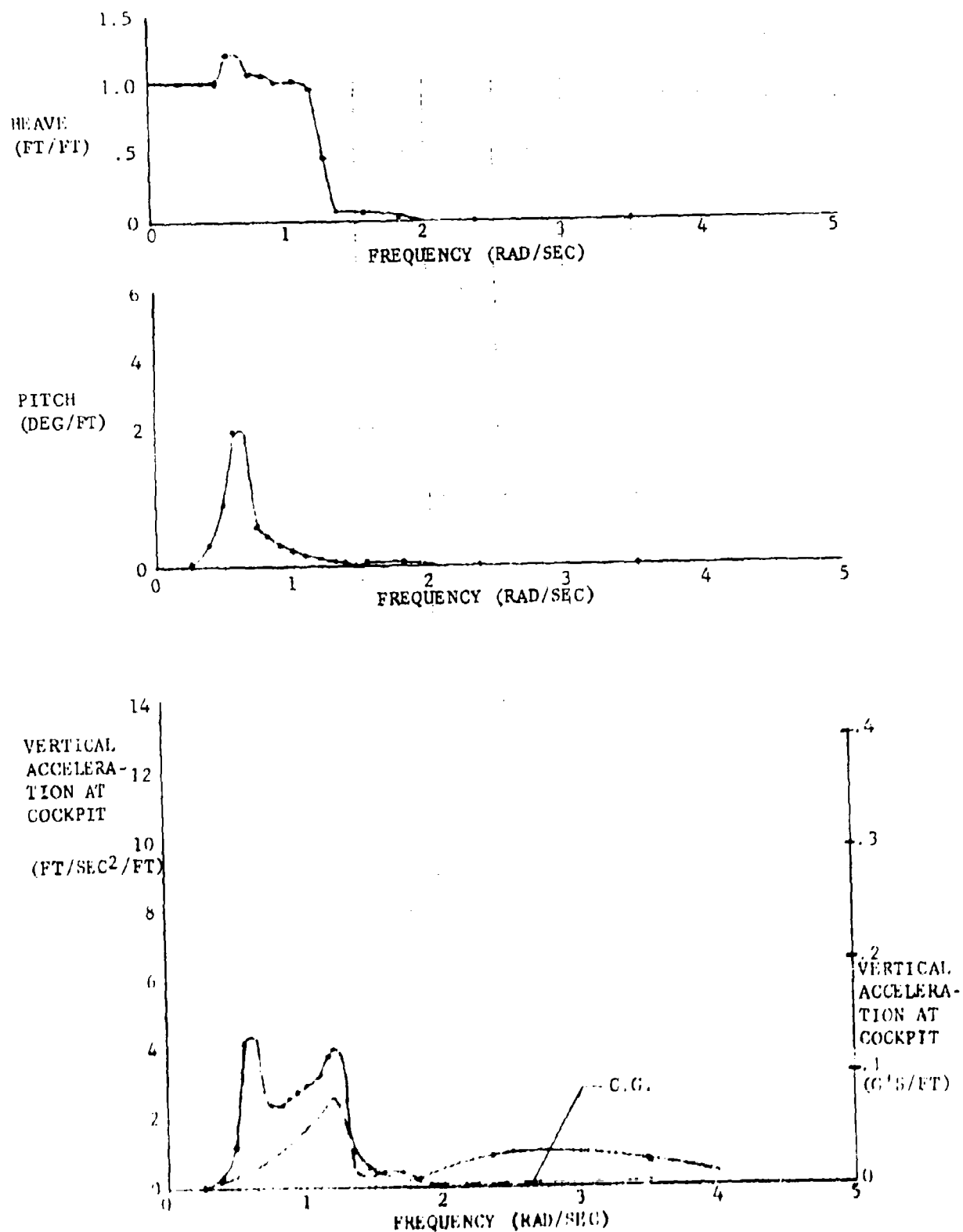


FIGURE 2. RESPONSE AMPLITUDE OPERATORS V = 5 KNOTS  
CONFIGURATION 1 CTOL CAT 1.25M

NR76H-137  
Appendix II

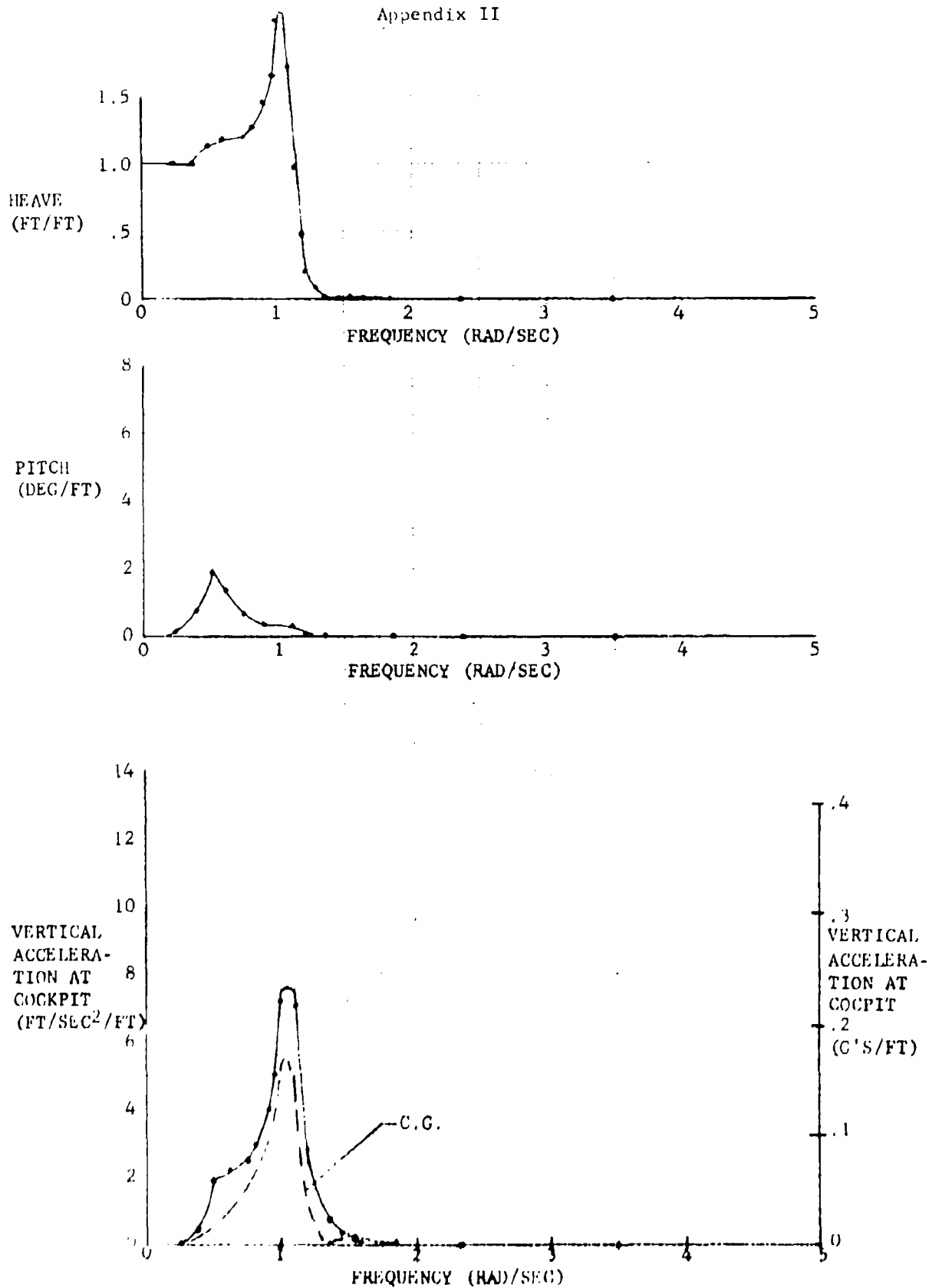


FIGURE 3. RESPONSE AMPLITUDE OPERATORS V = 10 KNOTS  
CONFIGURATION 1 C10L CAT 1.25M

NR76H-137  
Appendix II

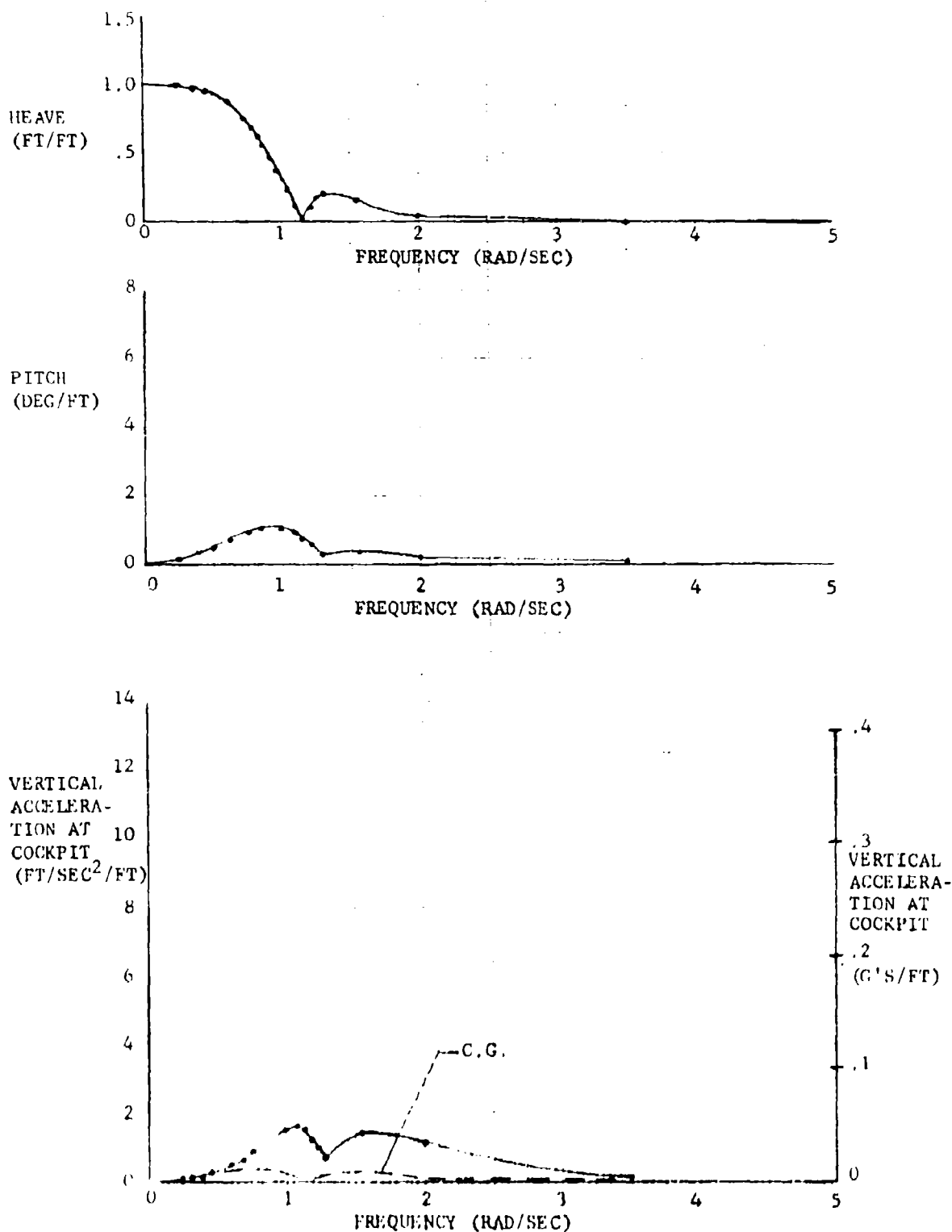


FIGURE 4. RESPONSE AMPLITUDE OPERATORS V = 0 KNOTS  
CONFIGURATION 2 CTOL S.H. 769H



NR76H-137  
Appendix II

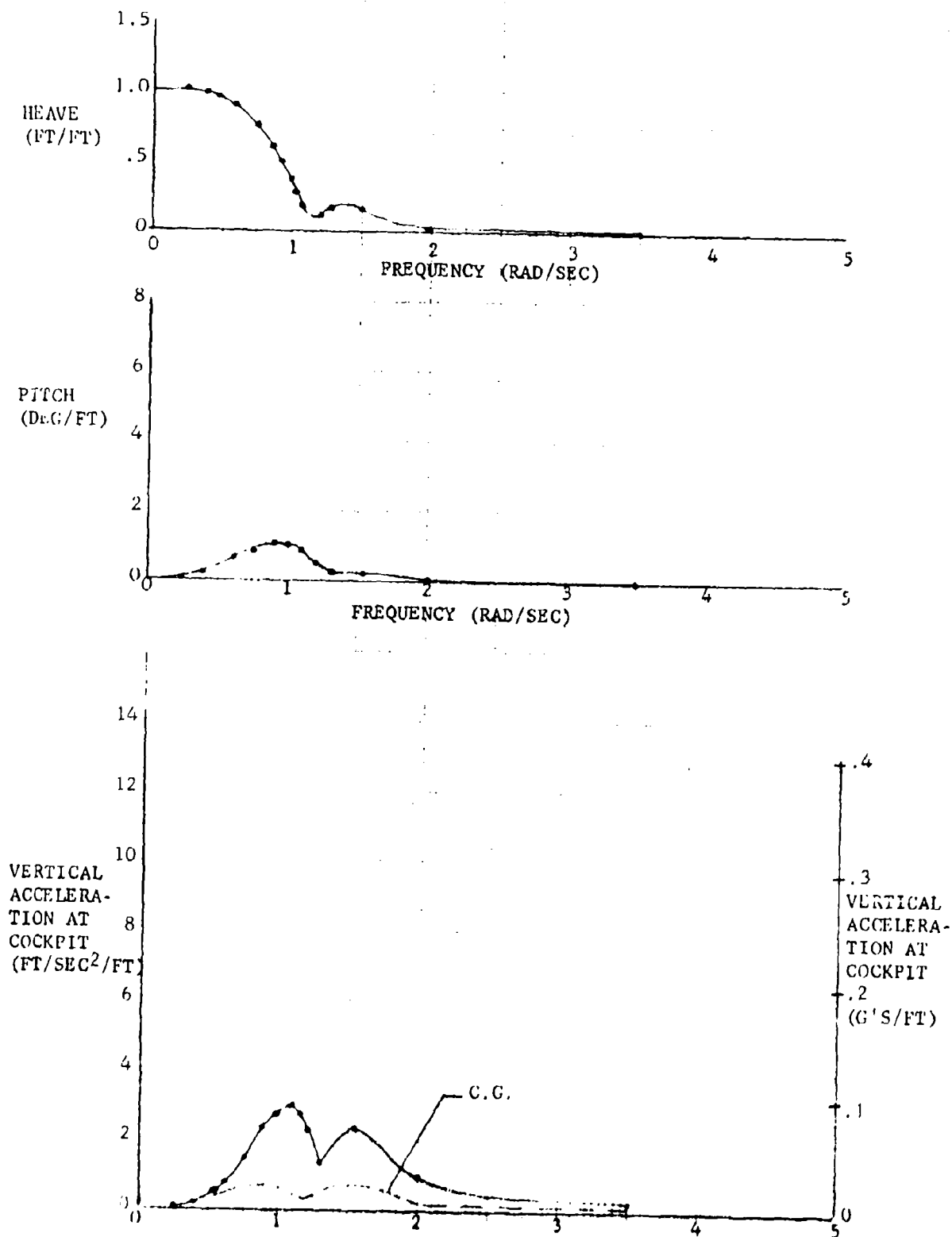


FIGURE 5. RESPONSE AMPLITUDE OPERATORS V = 5 KNOTS  
CONFIGURATION 2 CTOL 9.1. 769M

NR76H-137  
Appendix II

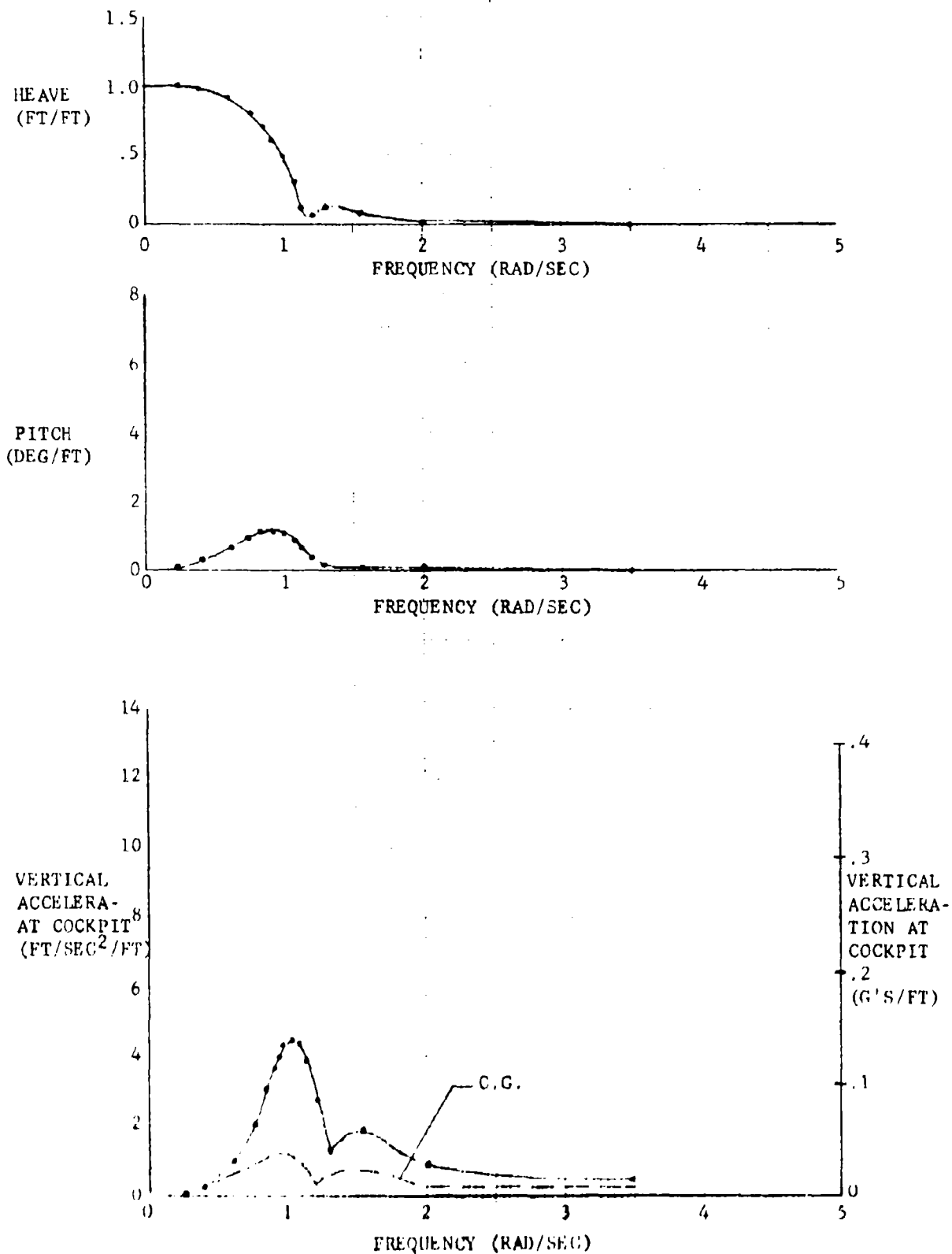


FIGURE 6. RESPONSE AMPLITUDE OPERATORS V = 10 KNOTS  
CONFIGURATION 2 CIOL S.H. .769H

NR76H-137  
Appendix II

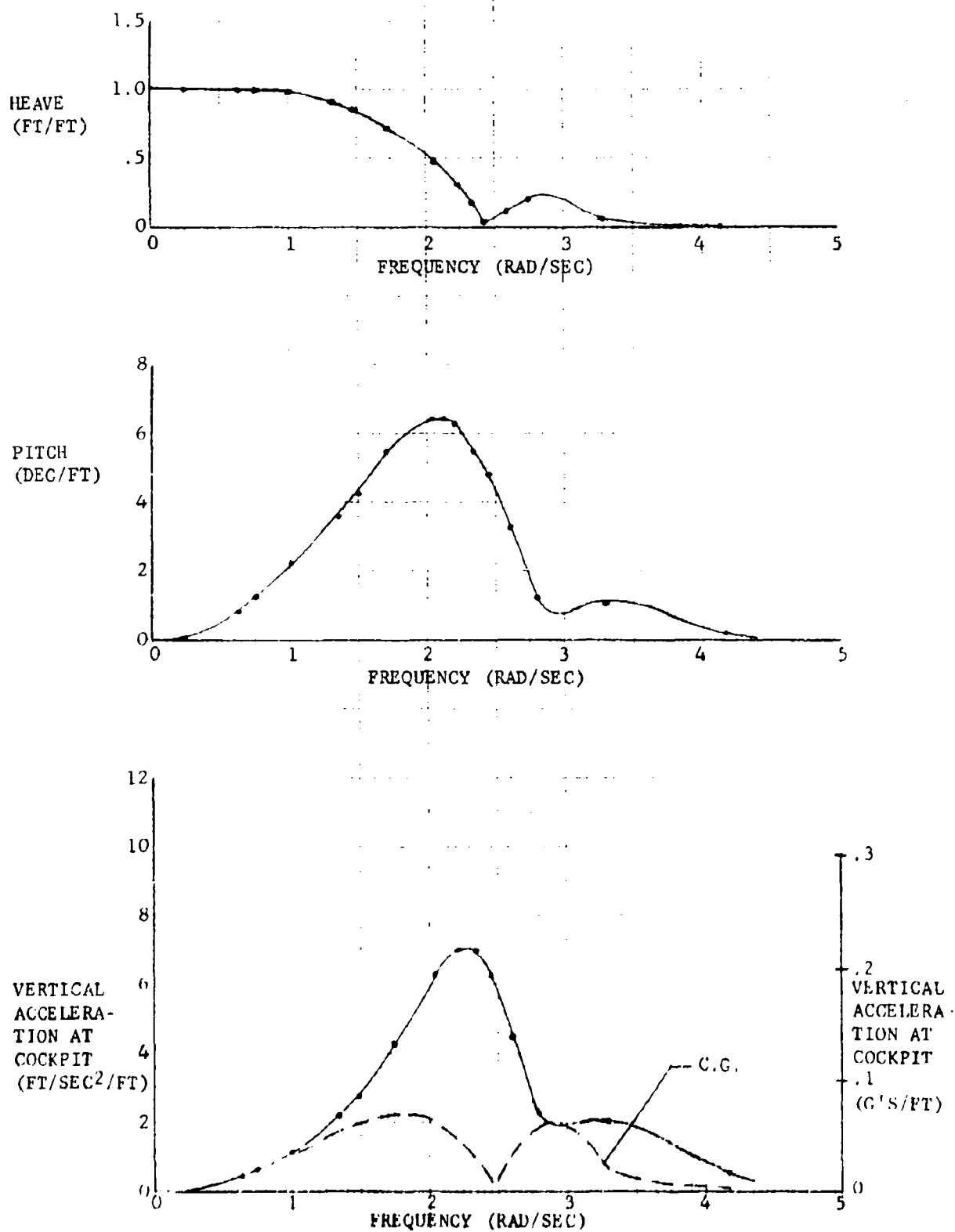


FIGURE 7. RESPONSE AMPLITUDE OPERATORS  $V = 0$  KNOTS  
CONFIGURATION 3 DTNRDC 40K

NR76H-137  
Appendix II

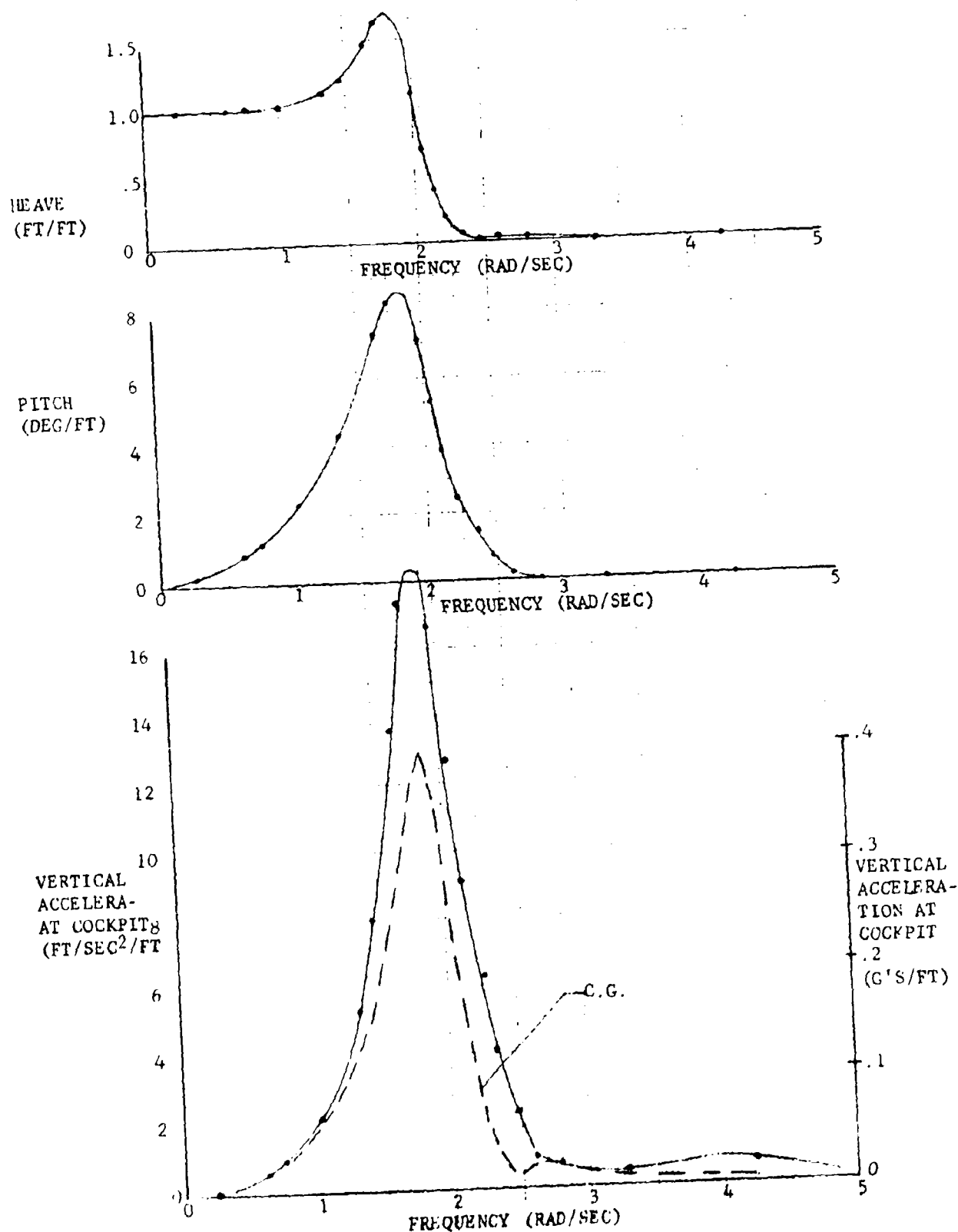


FIGURE 8. RESPONSE AMPLITUDE OPERATORS V- 5 KNOTS  
CONFIGURATION 3 DTNSRDC 40K

NR76H-137  
Appendix II

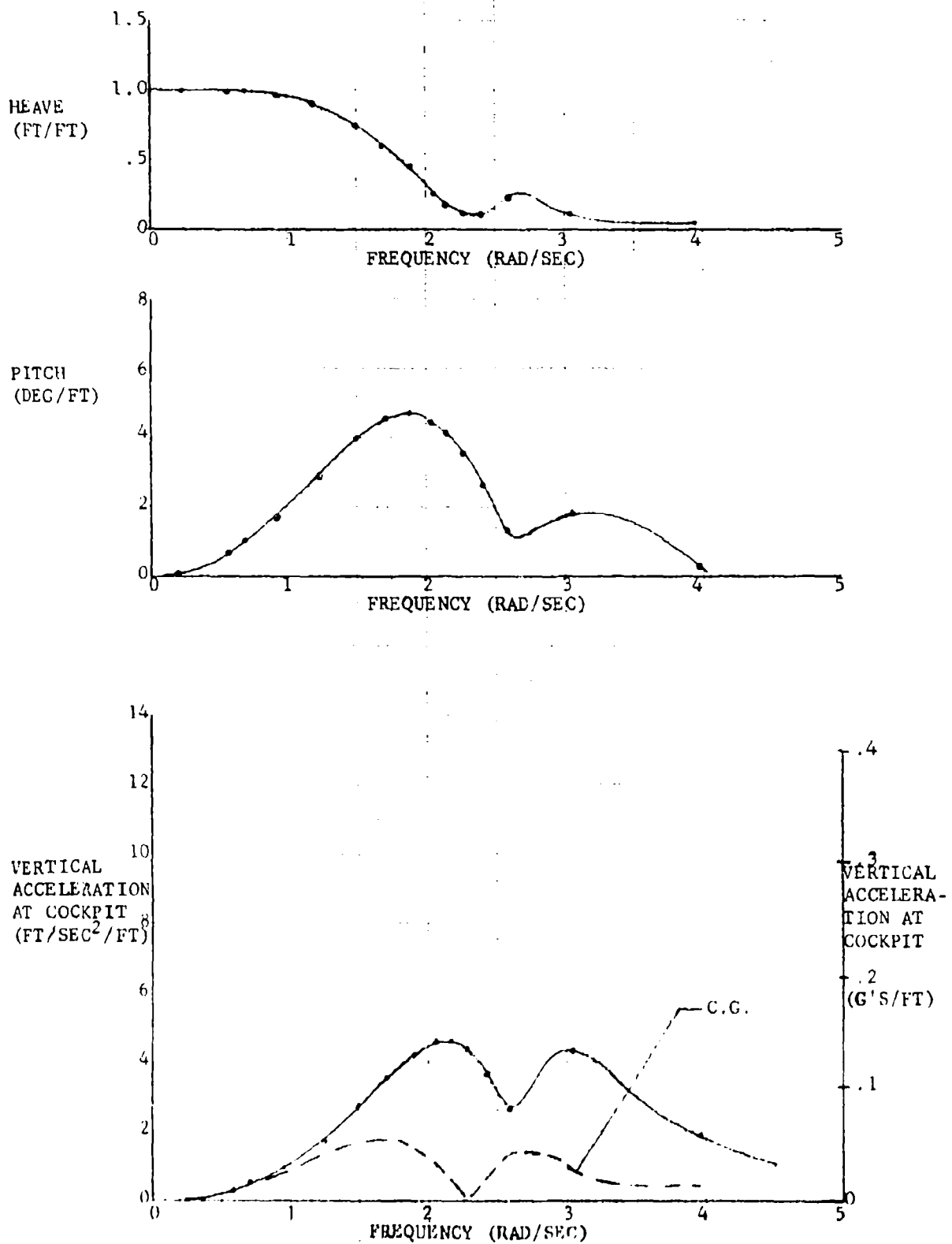


FIGURE 9. RESPONSE AMPLITUDE OPERATORS V = 0 KNOTS  
CONFIGURATION 4 X-WING 40K

NR7611-137  
Appendix II

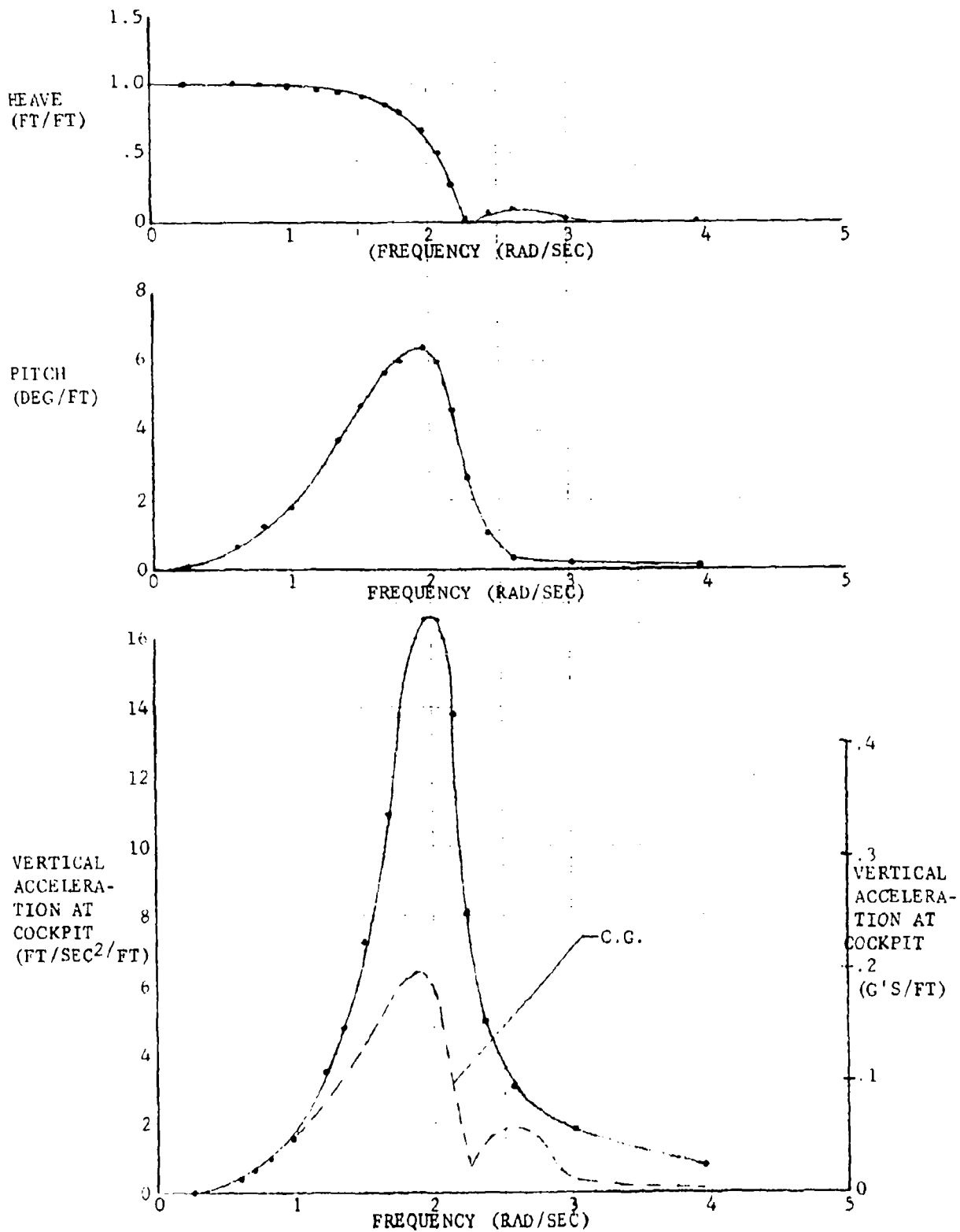


FIGURE 10. RESPONSE AMPLITUDE OPERATORS  $V = 5$  KNOTS  
CONFIGURATION 4 X-WING 40K

NR76H-137  
Appendix II

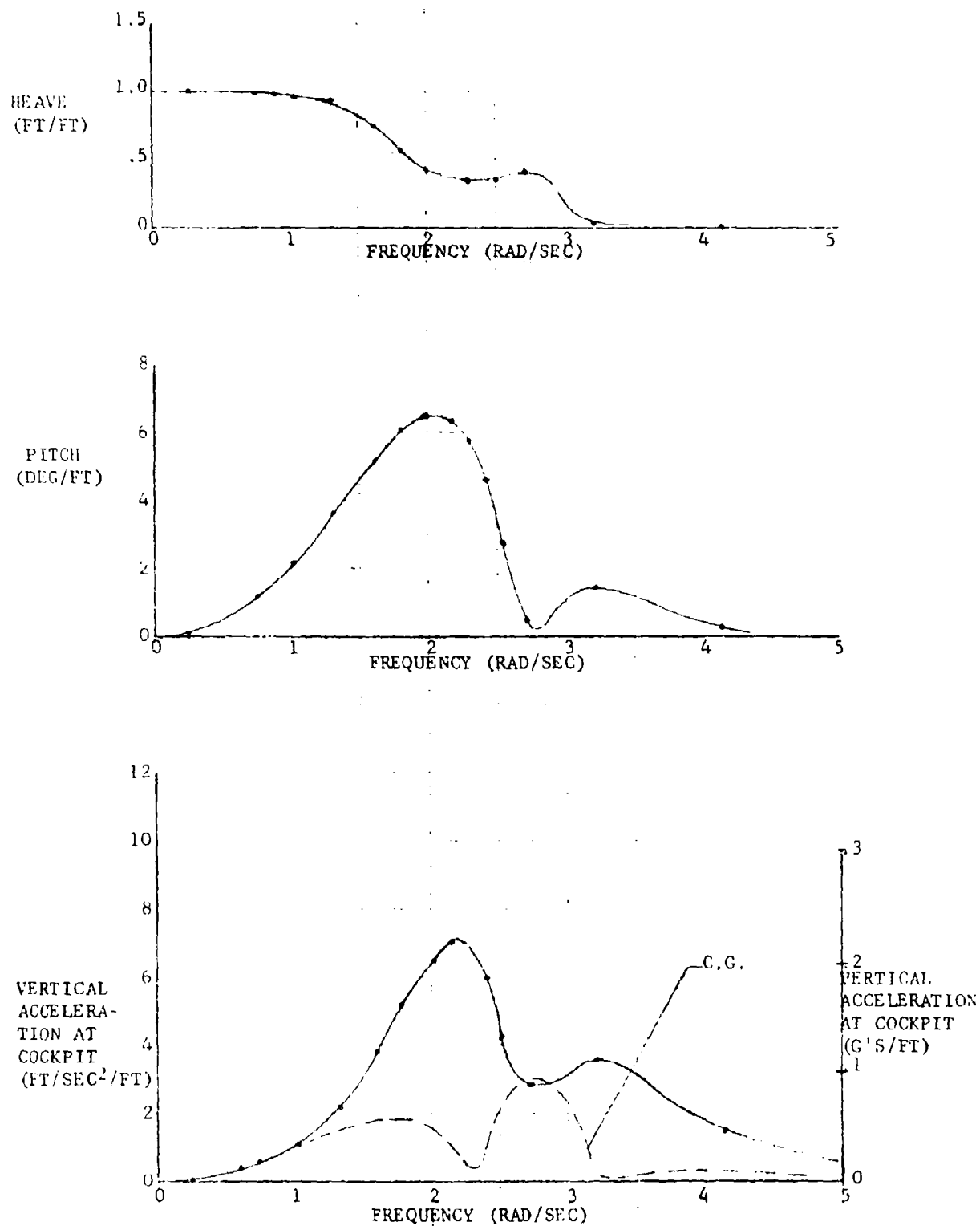


FIGURE 11. RESPONSE AMPLITUDE OPERATORS, V - KNOTS  
CONFIGURATION 5 T.B. 40K

NR76H-137  
Appendix II

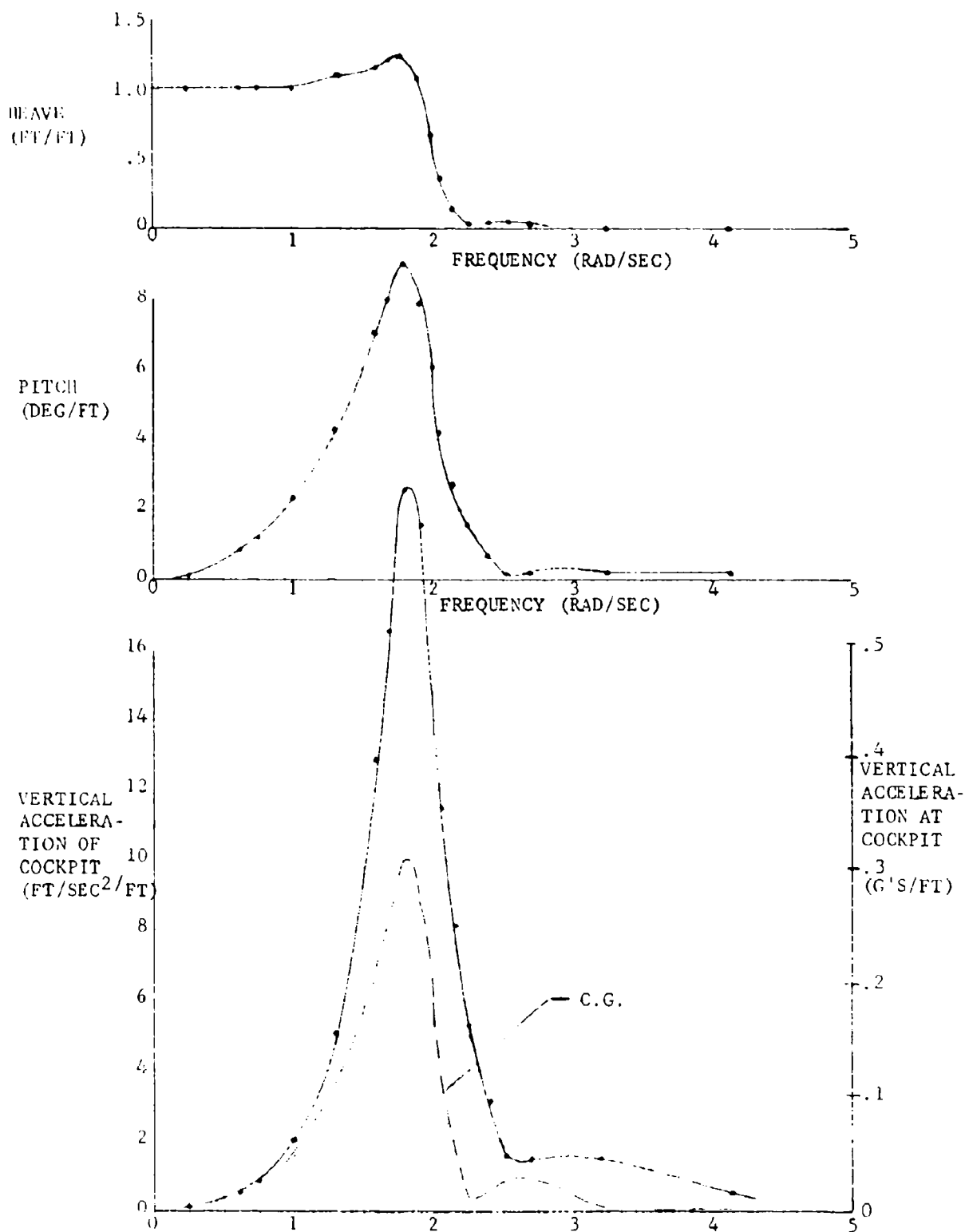


FIGURE 12. RESPONSE AMPLITUDE OPERATORS  $V = 5$  KNOTS  
CONFIGURATION 5 T.B. 40K



NR76H-137  
Appendix II

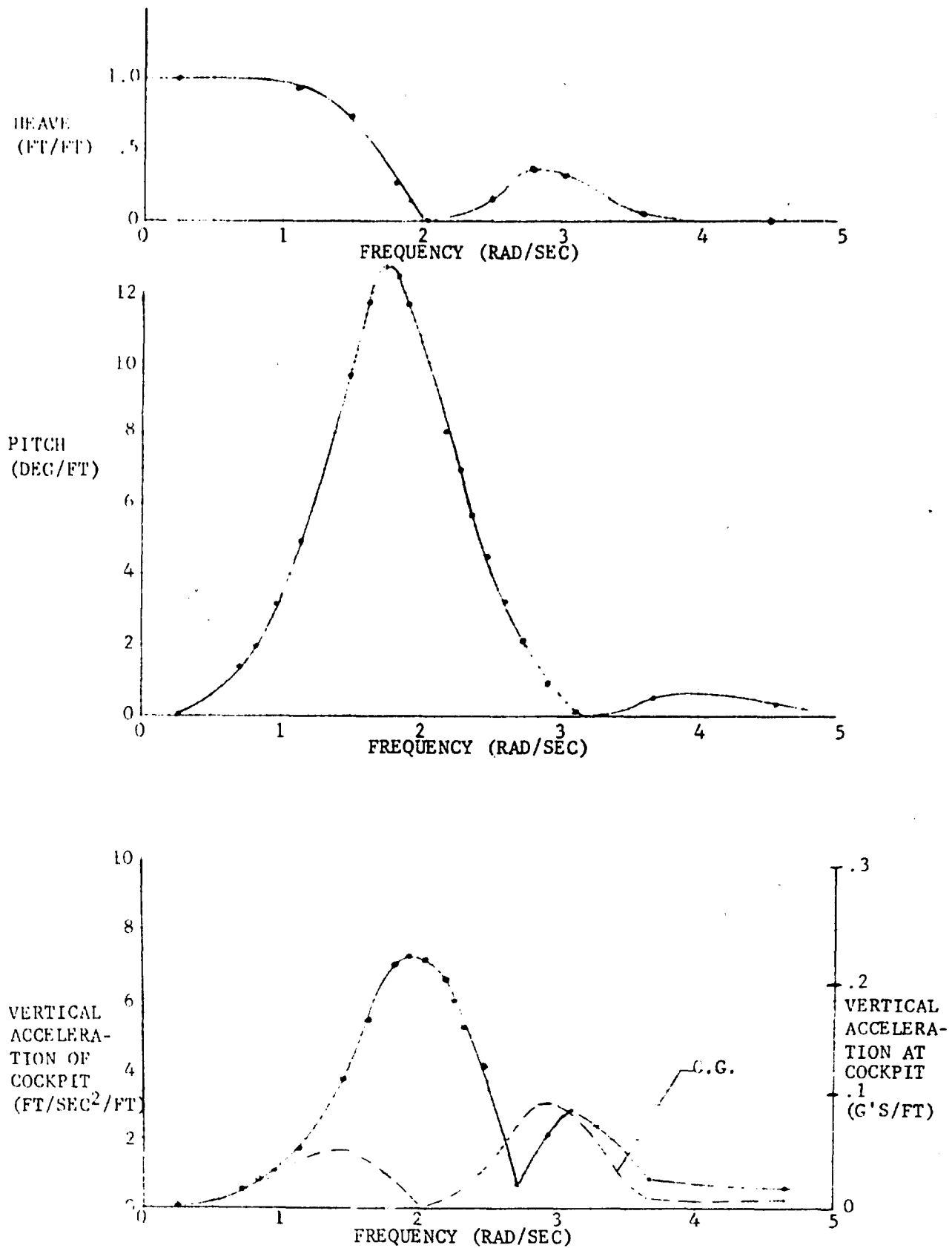


FIGURE 13. RESPONSE AMPLITUDE OPERATORS V - 0 KNOTS  
CONFIGURATION 6 T.B. 25K

NR/611-13/  
Appendix II

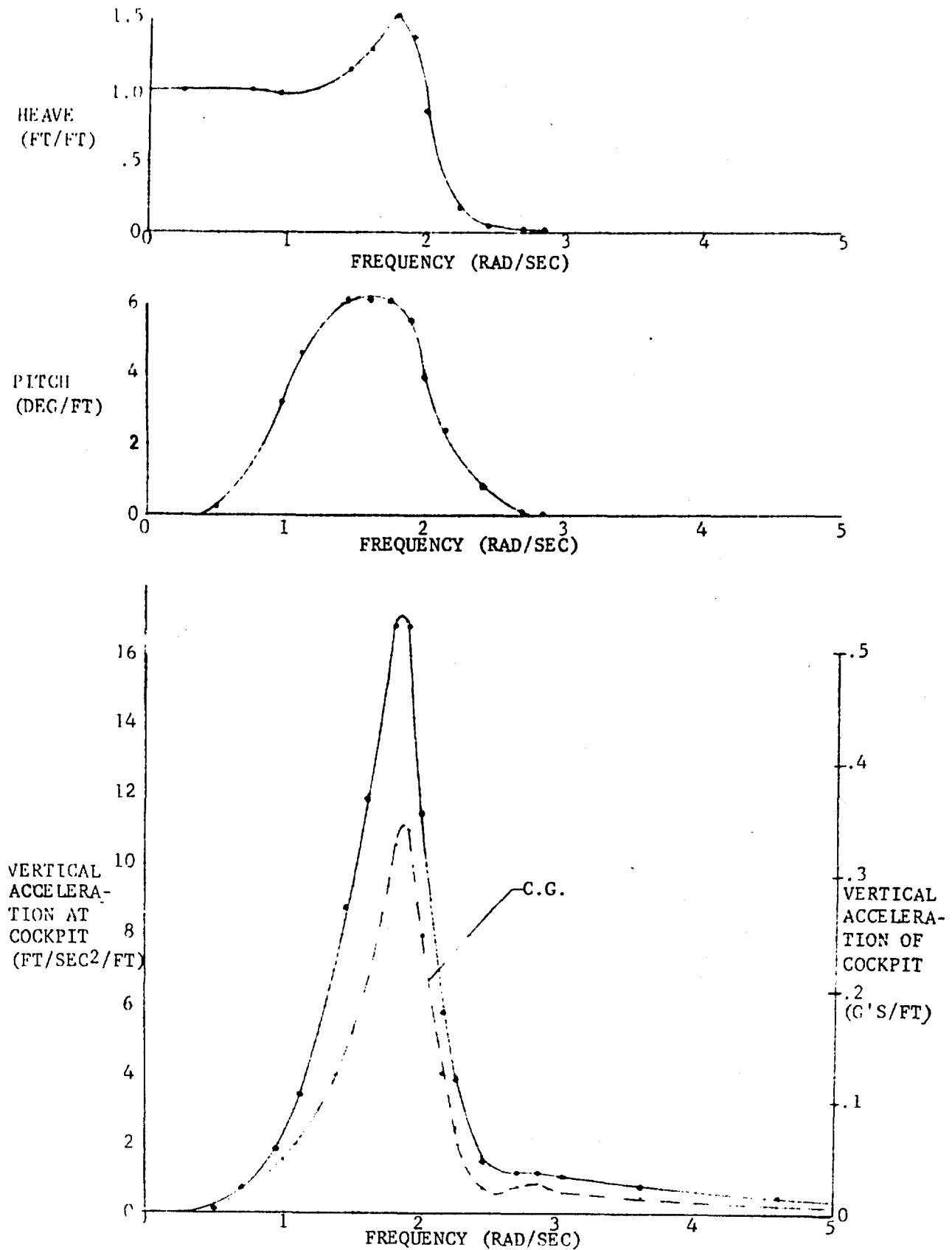


FIGURE 14. RESPONSE AMPLITUDE OPERATORS, V= 5 KNOTS  
CONFIGURATION 6 T.B. 25K

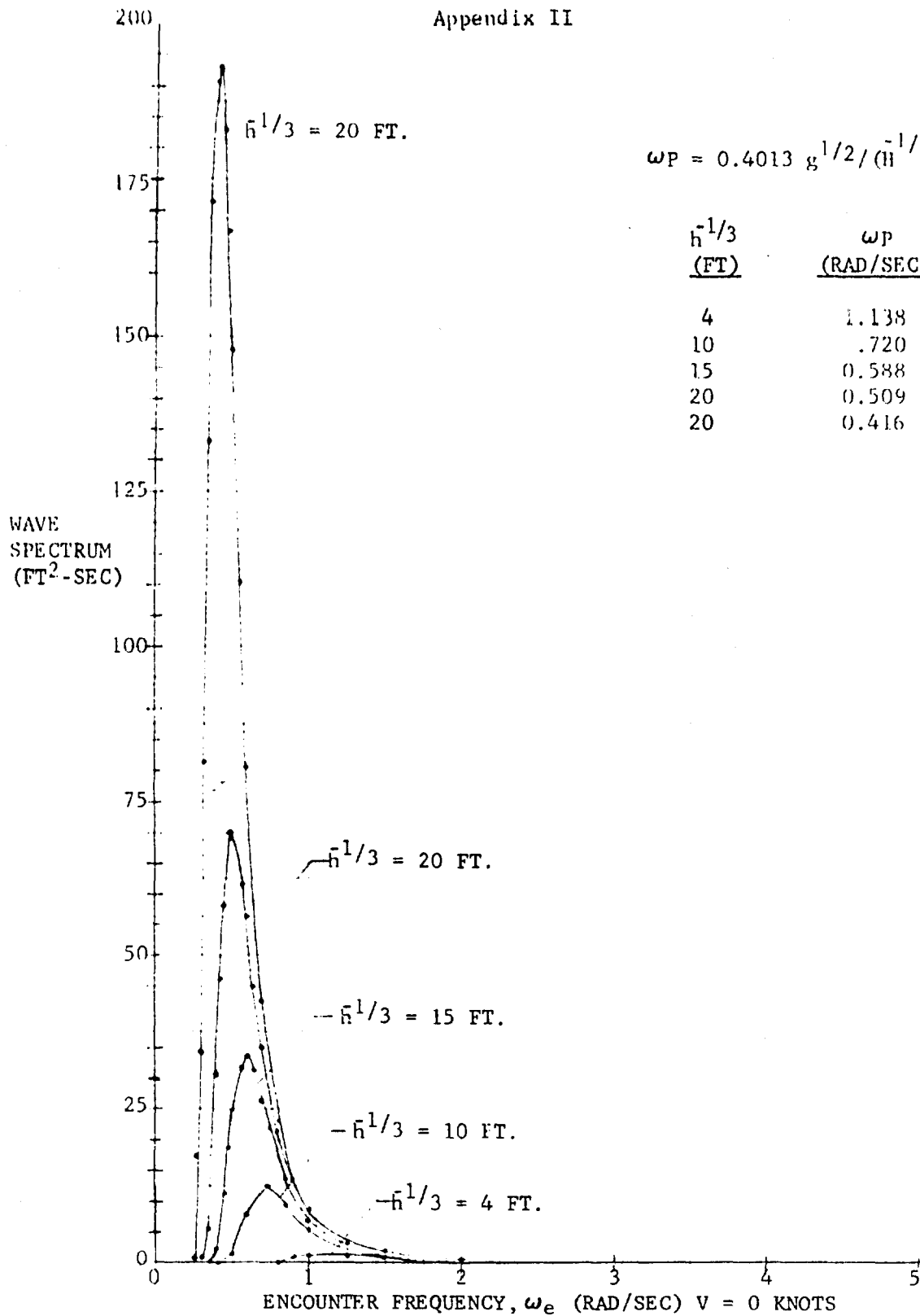


FIGURE 15. WAVE SPECTRUM VS ENCOUNTER FREQUENCY

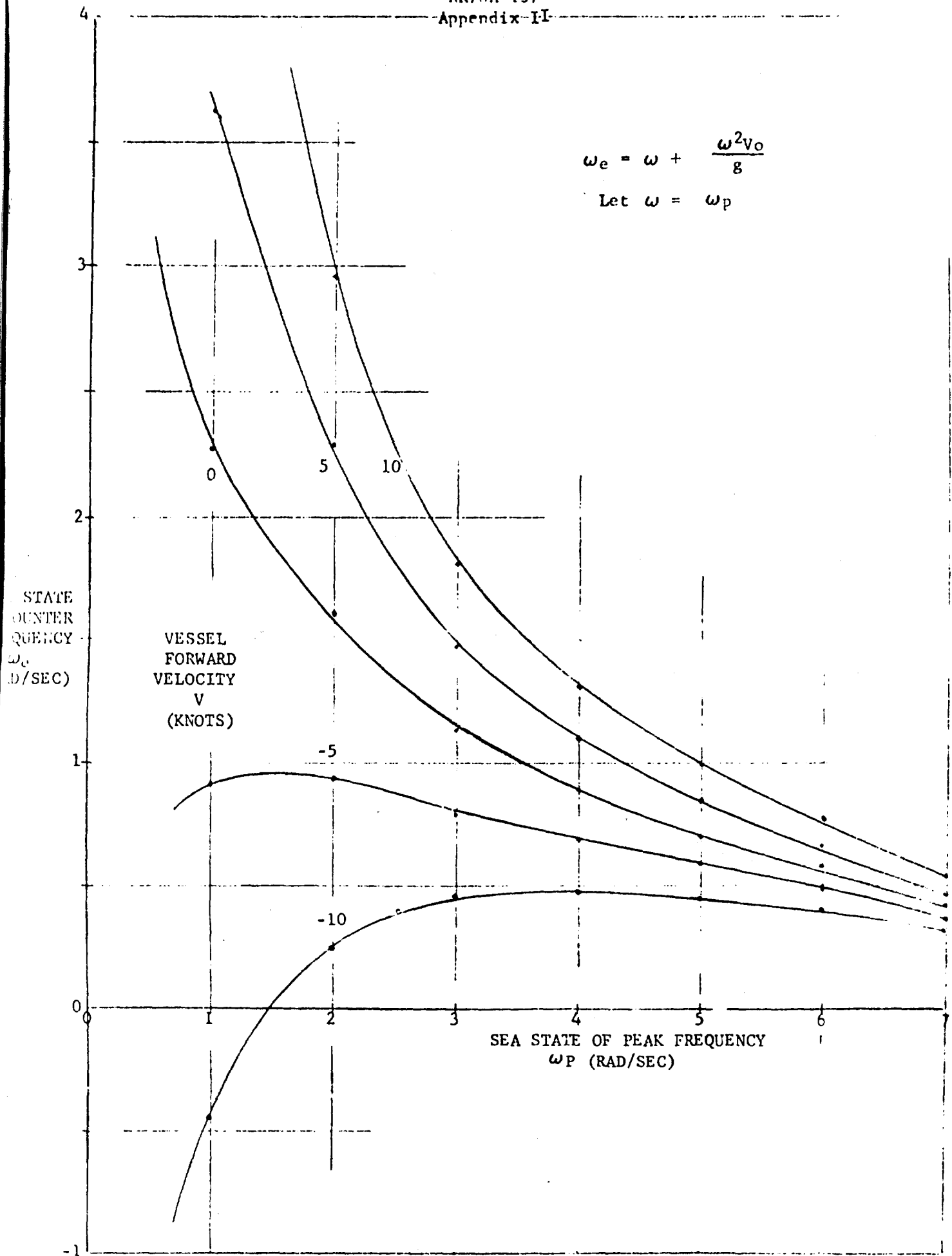


FIGURE 16. SEA STATE ENCOUNTER FREQUENCY VS SEA STATE  
II-18